BIG BEAR SOLAR OBSERVATORY

HALE OBSERVATORIES

CALIFORNIA INSTITUTE OF TECHNOLOGY
1201 East California Blvd.
Pasadena, California

"ATM Photoheliograph"

Contract NSR 05 002 071

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FOREWORD

The 65 cm Photoheliograph Functional Verification Unit (FVU) Program was conducted for NASA Headquarters under contract No. NSR 05-002-071. This program was performed under the technical direction of:

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This program was performed with the assistance of:

Ball Brothers Research Corporation, Boulder, Colorado
Muffoletto Optical Company, Baltimore, Maryland
Owens-Illinois Glass Company, Toledo, Ohio
Corning Glass Works, Corning, New York
Hale Observatories/Mt. Wilson Optical Shop, Pasadena, Calif.
Haskell Shapiro, Engineering Consultant, Corona del Mar, California
and others too numerous to mention

without whose assistance this project could not have been carried out.

ABSTRACT

This program has resulted in the design and fabrication of a 65 cm photoheliograph Functional Verification Unit (FVU) which has been installed in a major solar observatory. The telescope is at present being used in a daily program of solar observation while serving as a test bed for the development of instrumentation to be included in early space shuttle launched solar telescopes. The 65 cm FVU was itself designed to be mechanically compatible with the ATM spar/canister and would be adaptable to a second ATM flight utilizing the existing spar/canister configuration. This program has additionally served to stimulate development, under contracts from Marshall Space Flight Center, of an image motion compensation breadboard and a space-hardened, remotely tuned Hα filter, as well as numerous studies of solar telescopes of different optical configurations or increased aperture.

1.0 INTRODUCTION AND HISTORICAL BACKGROUND

This NASA sponsored program for development of a 65 cm Photoheliograph Functional Verification Unit (FVU) was taken over by Caltech following a NASA/JPL project which carried the FVU through detailed design of several, but not all, of its major subsystems. Funding under the Caltech program was initially used, after a competitive procurement, for a detailed design review, completion of the detailed drawings and fabrication to print by Ball Brothers Research Corporation (BBRC) under subcontract to Caltech. Improvements to the JPL design were implemented by modification to the original BBRC subcontract as deficiencies in the original JPL design became apparent. A simplified BBRC proposed alignment sensor subsystem was purchased, again after competitive procurement, in lieu of the original JPL design which was judged to be too complex and possibly unworkable. During Marshall Space Flight Center (MSFC) sponsored testing of the FVU, the means of remotely aligning the secondary mirror assembly was proven inoperable due to drive redundancies. A modified non redundant alignment drive eliminating remote control of the tilt function was designed, fabricated and integrated in the basic telescope. In the meantime a parallel contract to Caltech from MSFC was initiated to mount the FVU in the solar observatory at Big

Bear Lake, California to provide supporting data for ATM experiments being carried out in earth orbit. A vacuum tank system including a very good quality entrance window was procured under the MSFC contract to provide for mounting of the FVU.

Under the original FVU program, work progressed on developing an automatic exposure compensated stop action camera based on government surplus 35mm Mitchell movie film cameras which were readily available to Caltech. These cameras, while not space qualified, are reliable enough that they could be operated in a pressurized canister using relatively inexpensive control components and electronics. This approach, while not applicable to ATM, could be used for balloon flights and shuttle flights where retrieval of film is somewhat simplified over ATM. It has also provided the means of obtaining exposure data during ground-based testing sufficient to evaluate FVU image quality. The final work done under this contract provided for installation of beamsplitters, cameras, filters, etc. at the focus of the FVU and included the purchase of a Zeiss Universal Filter capable of scanning preprogrammed wavelengths in the 4000-7000 Å range with a bandpass of between 0.1 and 0.25 Å.

The FVU telescope is presently operational at BBSO in its vacuum tank with its own guider and offset drive control system. The Universal Filter has been installed along with either a Zeiss Hα filter of 0.25 Å bandpass, one of several Halle Hα filters of 0.5 Å bandpass or a Halle Calcium K-line filter of 0.3 Å bandpass. Provision has been made to mount a motorized Nikon camera for white light pictures or a silicon Vidicon TV camera capable of operating at Hα, also procured under this contract. Final determination of optical performance has been limited by seeing conditions so far but the summer of 1974 did yield some imagery of near ultimate resolution for high contrast subject matter. Testing of the primary mirror in the laboratory at Caltech after hand refiguring showed it to be between 1/5 and 1/6 wave, peak to peak. Rework of the primary mirror is planned during the winter of 1974-75 to improve its figure to 1/8 to 1/10 wave, peak to peak. A special report will be issued once the mirror is reinstalled following refiguring and after good seeing returns once again to BBSO.

2.0 TELESCOPE DESCRIPTION

The Photoheliograph FVU is a 65 cm aperture telescope of Gregorian design with an equivalent focal length of 3250 cm giving an f/50 image . The paraboloidal, thin cross-section, primary mirror was fabricated from C-101 Premium grade Cer-Vit and is hub mounted. This 250 cm focal length f/3.85 primary mirror was polished to a surface figure deviating from a true paraboloid by less than 1/8 wave peak to peak. A hole was bored through the mirror on-axis to aid in alignment of the optical system and to provide for mounting an alignment monitoring sensor. Since all chance of launch aboard ATM-B disappeared relatively early in the program, launch locks were not proved for the FVU primary mirror. Had they been provided, they would have been of the damping of energy absorbing type positioned at the mirror's edge rather than stiff, clamping, edge restraints that could have well subjected the mirror to even greater loadings than it would have experienced if unrestrained. The design of the mirror support was changed from the original JPL concept early because tests on a model indicated that the wedge shaped groove/collar assembly proposed could be predicted to generate a failure plane when any load, such as the mirror's own weight, was placed on the groove surface walls. Avoidance

of stress risers was nearly impossible in this design. Accordingly Muffoletto, at Caltech's direction, machined the mirror hub down to eliminate the grooves that had been originally provided for mounting and etched the rear of the mirror hub to further eliminate micro cracks from which fractures could proceed. BBRC then encapsulated the mirror hub in an Invar ring with spacing left for polyurethane bonding such that the inner diameter of the polyurethane cylinder is constant over a reasonable temperature range since the selected thicknesses of polyurethane and invar were calculated to be self-compensating for thermal variations. This entire operation degraded the mirror figure somewhat, necessitating removal of the enhanced silver coating and repolishing of its front surface. The primary mirror was recoated with aluminum after refiguring, to save on schedule and cost at that time. The primary mirror has since been subjected to a wide range of operating temperatures over the past year with no detectable problems resulting from this mounting technique apparent.

The secondary mirror is an ellipsoid situated 25 cm behind the heat stop mirror. The heat stop mirror, located at primary mirror focus, acts as a field stop for the system passing only the central 5 arc minutes of the image formed by the primary mirror. The near focus of the

ellipsoid is 25 cm corresponding to the location of the primary mirror focus. The ellipsoid far focus is 325 cm giving an image magnification of 13:1 at the film plane. This corresponds to a diagonal field of view of approximately 3.1 arc minutes of the sun's diameter in our standard 35 mm film frame. After the beam is reflected by the secondary ellipsoid it is directed to the instrumentation package by means of two folding mirrors (flats). In the ATM flight version the instrumentation would have been located in an adjacent quadrant. At BBSO, it is located outside and underneath the vacuum tank which contains the 65 cm optics and integrating structure. The integrating structure provides the means of axially and laterally positioning the primary and secondary mirrors and maintaining their proper relative positioning. The structure is of tubular, riveted construction and is fabricated from Invar for its low thermal expansion properties. The low thermal coefficient of expansion structure is firmly attached to the vacuum tank at its primary mirror end. The other end of the structure is allowed to float axially with respect to the vacuum tank which may itself change length over the temperature range experienced at BBSO. A zero thermal coefficient of expansion structure could be built for future photoheliograph versions by fabricating aluminum

rings which would expand or contract in diameter exactly compensating for the small but finite thermal expansion of the invar truss tubes connecting the rings. This zero coefficient property would be desirable for completely remote operation as would occur in space. At BBSO, where focus and alignment can be manually checked and corrected, the zero coefficient structure is not necessary. To minimize effects of differential misalignment between telescope structure and vacuum tank for various pointing attitudes, the telescope guider was clamped directly to the FVU structural rings inside the vacuum tank and fed through its own window in the end of the tank. It also floats axially at one end so that no strain is induced in the FVU structure through mechnaical redundancy. Guider offset is provided by laterally displacing the quadrant cell behind the guider telescope. The immediate result of displacement is an electrical output imbalance sensed by the quadrant cell. Servo electronics controlling the basic telescope drive then cause the entire telescope (including guider) to move in declination and right ascension until the output of the quadrant cell is balanced again. A similar guider system could be used for fine pointing the telescope mounted on a space shuttle pallet. The ATM would provide its own guidance as it does in the present design.

3.0 INSTRUMENTATION

Instrumentation originally proposed for the 65 cm ATM photoheliograph included beamsplitters and filters for recording data in broadband UV, broadband white light, and narrow band Hα with the possible addition of a vidicon monitor in Hα using the energy reflected from the heat stop mirror. Current thinking for a space shuttle flight includes a universal scanning filter, operating between 4000 and 7000 Å, a real time vidicon monitor (probably Hα) and a spectrograph. Early balloon-launched flights will include the spectrograph and either a Halle Hα filter or a scanning Hα filter and possibly a broadband (500 Å bandpass) white light camera. Cameras for balloon and shuttle-launched versions will record on 35mm film. This is partially because calcite elements for filters compatible with 70 mm film would be nearly impossible to procure and many times more expensive than those for 35 mm sized beams, even if available.

The cameras that have been developed under the FVU program are adaptations of standard Mitchell Movie Cameras produced for the film industry. These cameras were obtained as GSA excess property specifically for modification to provide stop action recording. Caltech has adopted a stepper motor drive to advance the film and operate the shutter over a

wide range of speeds. A photocell is introduced into the light path to provide for the control of shutter speeds. Shutter angle must still be manually set to the median range corresponding to the film/filter combination chosen and requires an equivalent pot adjustment to maintain the desired film density. The shutter speed servo operation possesses sufficient range to work within the universal scanning filter range but requires electronic logic coupling the selected spectral range with the output signal from the exposure controller photocell to compensate for film sensitivity variance over the spectral range. The electronic logic for this operation is being designed at present for use at BBSO and will be available for the future space flight of a universal scanning filter. However, a flat response version of SO 392 film is being developed by Kodak which could minimize the requirement for spectral exposure compensation.

The universal scanning filter was procured from Carl Zeiss, Inc., Oberkochen, Germany and is nearly identical to the one provided to Dr. Jacques Beckers at Sacramento Peak Observatory, Sunspot, New Mexico. Its design precludes use in a space environment without repackaging of electronics to provide for thermal control without convection cooling. Basically the scanning universal filter is a birefringent

device which can be programmed for any wavelength between 4000 and 7000 Å with a bandpass between 0.1 and 0.25 Å wide at the selected wavelength. The number of lines capable of being tracked is limited by the number of prefilters available (six) in this configuration. Prefilters may be manually substituted. Each prefilter is spectrally wide enough to allow limited off-band scanning around the line selected. Thus, while the filter is theoretically capable of continuous scanning over the entire wavelength region from 4000 to 7000 Å, in reality the number of prefilters that packaging allows will determine the percentage of the total range covered. These prefilters would be picked to correspond with selected solar absorption or emission lines. In order to provide the correct mutual alignment of all internal elements as well as prefilters, a small, specialized computer/programming unit is required. This is contained in an equipment rack which must be repackaged and installed aboard the ATM or space shuttle if the filter is to be flown. The unit procured under this contract must be considered a breadboard unit due to the extensive repackaging and specialized scan programming functions that must be provided for a flight unit, not to mention true space hardening of the entire unit. However, it is a very useful tool and can be used for purposes

of packaging design and provision of automated scan programming functions. Results obtainable under average spring seeing conditions at BBSO are shown in accompanying figures.

In addition to the scanning universal filter, a number of Halle Hα filters (0.5 or 0.7 Å bandpass) were procured along with a Halle K-Line filter (0.3,0.6, or 1.2 Å bandpass). These filters provide for manually selecting wavelength and can be used on early flights for instrument evaluation. In addition, NASA explored the possibility of a scanning Halle Hα filter in a study contract with Ball Brothers Research Corp., Boulder, Colorado. Caltech assisted in this project by providing an older Halle Hα filter for the repackaging effort. The resultant is a filter of 0.25 Å bandpass capable of scanning from plus to minus 2 Å off centerline. The scanning is accomplished through use of a stepper motor with ten-turn pot. Its output gives a precision of approximately 1/100 Å in selected wavelengths. The complete scan from plus to minus limits requires approximately 30 seconds plus any exposures made during the scan (provided the scan is stopped). This filter was evaluated at BBSO during the summer of 1974 and will be available for instrument evaluation flights when the balloon or space shuttle is launched.

4.0 TEST AND EVALUATION

The FVU and its mechanical and optical subsystems were subjected to testing both during and after component fabrication and after subsystem integration was completed. A large part of the test effort was associated with the optics, principally the primary mirror. During and after fabrication the primary mirror was subjected to knife edge and Hartman screen testing which, to those who viewed it, indicated that the specified one-eighth peak to peak wave performance was observed. Unfortunately these tests were very subject to Schlieren. Since the optical subcontractor, Muffoletto Optical Co., had no vacuum test facility, no adequate substantiating photographs could be obtained of the knife edge test due to Schlieren. Following completion of the primary mirror, repetitive testing and failure of the machined groove in the Cer-Vit mirror hub model supported by the invar V-ring indicated a very likely catastrophic failure mode for the primary mirror which necessitated redesign of the mirror mount. This in turn dictated turning the hub of the primary mirror down to eliminate the groove induced stress risers that could lead to failure. To make doubly sure that no micro cracks remained, the entire hub and part of the

rear surface of the primary mirror were immersed in a hydrofluoric acid etch bath. While the procedure and the redesign which preceded it appear to have eliminated the failure mode, the polished figure of the mirror front surface apparently was adversely affected. This was not discovered until LUPIgrams were obtained at BBRC in a test program sponsored under another MSFC contract. However, the BBRC testing was done in a vacuum tank at a time when FVU secondary assembly alignment was almost impossible. Rather than depend on results extrapolated from a misaligned FVU test state, Caltech elected to accept delivery of the FVU in Pasadena where additional testing could be undertaken. Upon its arrival at Caltech in early 1973, the FVU was placed in a specially prepared room free of heating and of ventilation drafts and positioned on a framework set upon three Barry mounts to provide for shock and vibration isolation. The test flat, LUPI and FVU were all supported on the framework. LUPIgrams of the primary mirror indicated that benefit could be derived from repolishing the primary mirror. This polishing operation was accomplished at Caltech in the same room used for testing so that frequent LUPI and knife edge tests could be photographically recorded to show progress. Once optical performance between one fifth and one sixth wave was attained, no further hand polishing appeared advisable within the

limited time remaining prior to ATM launch. The mirror was then washed and aluminized. Tests were conducted in each of the three possible rotational orientations. No gravity effects on mirror figure could be detected from inspection of these LUPIgrams. That is to say that all irregularities remaining in the mirror surface rotated with the mirror. No local optical coating house was willing to replace the original enhanced silver coating on the mirror within reasonable schedule and price constraints so the decision was made to coat it with aluminum instead. While aluminum is a less efficient reflector in the visible it does allow performance extension further down into the near UV than does enhanced silver. The secondary mirror retains its original enhanced silver surface coat.

Tests of the optics conducted while installed at BBSO have been inconclusive. Schlieren have prevented obtaining conclusive results from point source testing using stars, and the unusually poor seeing conditions limited the resolution of solar imagery obtained in 1974. Individual frames of the sun obtained simultaneously with 10" telescope images of the same area have on occasion been of better resolution than those of the 10" telescope but it is felt that these images were seeing limited for both telescopes. Some high contrast

white light images of resolution approaching 1/4 arc second were obtained.

Testing of cameras and filters at BBSO has, on the other hand, progressed steadily. For example, operational testing has demonstrated thermal control deficiencies in the Halle filter design which necessitated further insulation and an external heater for operation under winter conditions at BBSO. Refinements would similarly be required for orbital operation. Also, improvements in control flexibility for the automatic exposure control were made as a result of day to day camera operation in a variety of observing sequences using different film/filter combinations. This has in turn suggested pre-programmed approaches to camera control corresponding to specific film/filter combinations that would be suitable for space shuttle computerized instrument control. This approach would be especially applicable to proposed manned observational programs for orbital versions of the photoheliograph.

5.0 CONCLUSIONS

The experience obtained in designing, fabricating, testing and operating the FVU has led to a number of conclusions, and recommendations for modifying the FVU design. Based upon when these conclusions were reached either: 1) changes were incorporated during the FVU design, 2) the FVU hardware was modified after fabrication to incorporate them, 3) the FVU modifications are proposed for eventual incorporation at BBSO, or 4) the recommended modifications would be incorporated in future versions of the photoheliograph but, for schedule, priority, or monetary reasons, not in the FVU at BBSO.

5.1 MODIFICATIONS INCORPORATED DURING THE FVU DESIGN

A number of modifications to the FVU design originally provided by JPL were incorporated prior to completion of design details by Ball Brothers Research Corporation (BBRC). Of these, a number were made for manufacturing ease, several for the purpose of reducing overall subsystem weight, a number to correct minor design deficiencies associated with the mounting of optical components, and one change, the on-axis alignment sensing subsystem, represented a totally different and simplified approach to the design requirement.

The on-axis design concept for alignment sensing has since been adopted by other systems contractors in NASA sponsored studies of large scale photoheliographs.

5.2 MODIFICATIONS INCORPORATED AFTER INITIAL FVU FABRICATION

Modifications incorporated after initial FVU fabrication were more extensive in scope than those incorporated during the design phase. They include the following: Testing revealed that drive redundancy caused mechanical binding and eventually failure of the secondary assembly alignment drive. This was a very serious problem which had originated in the initial JPL design concept. Space and existing design limitations did not allow much freedom of choice in selecting a design solution. Finally, BBRC recommended and Caltech approved a design approach relying on leaf springs to provide return pressure against driven wedges which provided the desired displacement in each of two axes. Tilt alignment was separately provided internally around the secondary mirror holder itself although it is only manually adjustable. Focus adjustment is also provided within the secondary mirror housing. It is motor driven and, unlike the original design, cannot interact with tilt alignment since a single motor provides the desired displacement along the optical axis of the secondary.

An adaptation of the new system would be applicable for space flight since this concept is designed to operate in vacuum.

The mounting of the primary mirror was changed from a V-groove/collar assembly to polyurethane potting of a smooth mirror hub in an invar ring. If the hub mounted mirror is used for space application this method of mirror mounting is recommended.

The mounting of the second diagonal mirror assembly was changed from being cantilevered off the telescope structure to a totally independent two axis motor controlled mount bolted to a hat section of the vacuum tank within which the FVU now resides. Similarly, the instrumentation package was physically removed from the FVU structure and is bolted to the outside of the above mentioned vacuum tank. An active cooling plate was provided directly behind the primary mirror to provide a heat sink for the thermal control of the primary mirror, if necessary. However, tests have not yet indicated the necessity of providing this cooling plate.

5.3 MODIFICATIONS PROPOSED FOR INCORPORATION AT BBSO IN THE FUTURE

Two major modifications will be made to the FVU in its BBSO mounting and a third one is being planned for inclusion if the optical performance of the 65 cm FVU system at BBSO appears to warrant it.

In the winter of 74-75 two modifications will likely be made. First, a new lower magnification secondary mirror will be installed. It may be held in a new secondary pod designed for passive cooling of the heat stop mirror. The lower magnification will enable matching telescope resolution more nearly to the atmospheric seeing conditions present in the wintertime. Should the alternate thermal control approach be selected, it will allow evaluating a passibely cooled heat stop provided with adequate radiator area. The existing FVU design did not operate satisfactorily with passive cooling and, in fact, required recoating of the heat stop mirror which had been badly darkened by the sun's image. The design for a passively cooled heat stop was conceptualized in an MSFC sponsored study by Ball Brothers Research.

Second, the Bendix Corporation Image Motion Compensation (IMC) device designed and fabricated under another MSFC contract will be adapted for fine guiding the FVU second diagonal mirror or a special reference mirror during the spring of 1975. Its time response is theoretically fast enough to compensate for some gross atmospheric seeing effects, low frequency vibration effects due to combinations of long image path and large telescope inertias and performance limitations of the existing 65 cm FVU guider and its servo drive. The IMC

is thought to be particularly necessary in orbit where spacecraft and instrument pointing state-of-the-art may limit resolution over long exposure times.

The third modification at BBSO concerns the possible requirement for servoing temperature control of the perimeter of the large vacuum tank window to match its temperature on the optical axis if it is determined that the window's thermal performance is limiting overall resolution capability. While a window is not required for space flight, a balloon-borne version of the photoheliograph will most likely require mounting in a vacuum tank in a manner similar, technically, to the BBSO installation.

5.4 MODIFICATIONS RECOMMENDED FOR FUTURE VERSIONS OF PHOTOHELIOGRAPHS

A number of modifications have been proposed for future versions of the photoheliograph but have not been selected for inclusion on the existing 65 cm FVU due to factors including cost, downtime, limited benefits for an earth-based observatory, and limitations of the observatory structure and mount at Bug Bear. A few of these modifications are described below:

1) Replacement of the FVU truss structure with a thermally self-compensating aluminum-invar structure of diameter

sufficiently large to eliminate the need for light baffling the individual structural rings or elimination of the truss altogether.

2) Replacement of the existing heavy vacuum chamber and thick aperture window with one of thin wall-or composite structure which could serve as the photoheliograph structural base in addition to providing a vacuum pressure differential for thermal control at balloon altitude and to eliminate condensation on optical surfaces during recovery. The aperture window could be thinner only if low differential pressures were maintained. This reduction in thickness in turn would somewhat relax the extremely tight homogeneity requirements on the window blank since effects of inhomogeneity are proportional to thickness.

3) Provision for remote control of all necessary alignment adjustments which would not be accessible during balloon or space operation. Such remote control is not necessary for operations conducted in an earth-based observatory.

4) Development of space qualified (with respect to vacuum, thermal, and vibrational environments) cameras, filters, beamsplitters and other optical and electro-optical components of the detection subsystem. Consideration must be given to whether these components will be used in a space shuttle-launched flight experiment or aboard a balloon-launched

test flight. In some ways the balloon test flights will impose additional or at least different requirements for photoheliograph subsystems although the cost of developing hardware for a balloon flight would be considerably less costly due to the elimination of all man-rated requirements that the shuttle must impose for safety. It is this differential that makes the balloon flight cost effective as a precursor to the eventual shuttle-launched flights of the early 1980's. Of course, the shuttle concept itself represents a very real cost advantage over the old "one shot and it's got to work" philosophy that dictated hardware requirements for OSO and to a large extent Skylab/ATM experiments.

FIGURE CAPTIONS

Figure 1: Broadband White Light Photograph of Sunspot Group. The best resolution on this photo corresponds to ~ 0.3 arc seconds. Note detail in the penumbra and certain of the small granulation structures. Even this high-speed photograph shows non-uniform resolution due to instabilities in the earth's upper atmosphere.

Figure 2: On-band H-α Photograph of Sunspot. This and the off-band H-α photograph following are limited by seeing conditions and overfilling the birefringent filter which results in light scattering within filter elements.

Figure 3: Low-Contrast Photograph of Sunspot in Off-band H-α. The contrast and resolution are typical of combined mediocre seeing, overfilling of the birefringent filter and minor vignetting due to misalignment of the beamsplitter directing the beam to the filter.

Figure 4: Early H-α Photo of Sunspot Group. Low contrast is due to seeing limitations and overfilling of birefringent filter. Even with the limitations mentioned above, the resolution was comparable with the performance of the 10" refractor on the same day. Note non-uniformity of resolution over the field due to turbulence in the earth's upper atmosphere.

Figure 5: Folded Gregorian Optical Concept

Figure 6:	Internal Alignment Scheme
Figure 7 through 14:	Photographs of the 65 cm Photoheliograph during fabrication and assembly at Ball Brothers Research Corporation, Boulder, Colorado.
Figure 15:	Details of the original JPL Secondary Alignment Drive concept whose redundancy caused failure of flex rods and binding of the assembly. An improved secondary assembly support and drive was designed and fabricated by the subcontractor and has operated satisfactorily for over one year.
Figure 16:	65 cm FVU at BBRC after integration of improved secondary assembly support.
Figure 17:	View of BBSO Telescope Cluster. A. 10 inch B. 8.6 inch C. 65 cm D. Hasselblad White Light.
Figure 18:	Detail of Front End of 65 cm Telescope showing: A. Vacuum Tank B. Aperture Window C. Sunshade D. Safety Shutter.
Figure 19:	Detail of 65 cm Telescope Entrance Window. Note coolant lines at arrows.
Figure 20:	65 cm Telescope East Optical Bench showing: A. Mitchell Stop Action Camera B. Auto Exposure Control.
Figure 21:	Zeiss Universal Filter and Controller ready for installation.

Figure 22: Zeiss Universal Filter Installed on 65 cm Telescope East Bench.

Figure 23: Vacuum Pumps for: A. 10" and 65 cm Telescopes

B. 8.6" Telescope

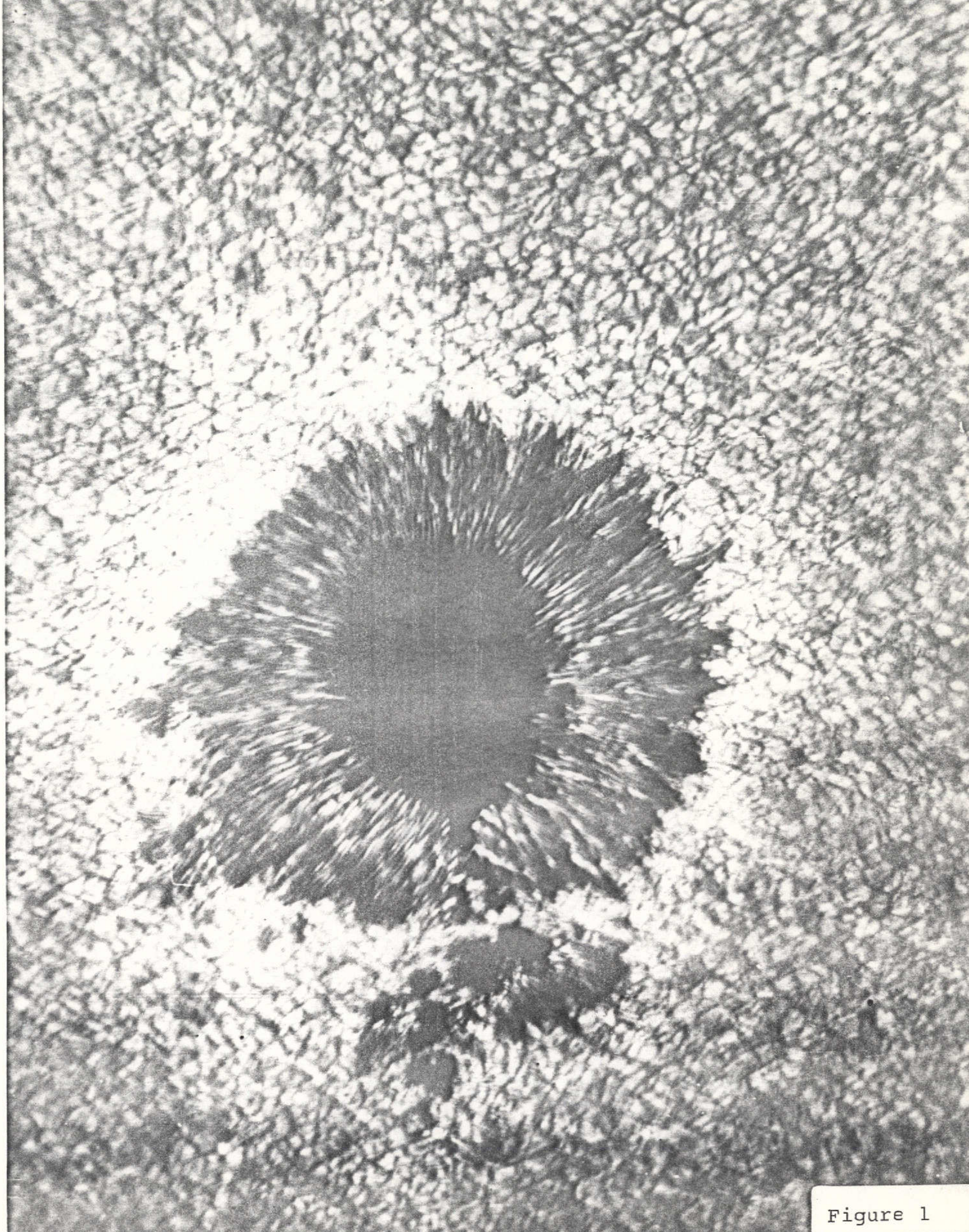
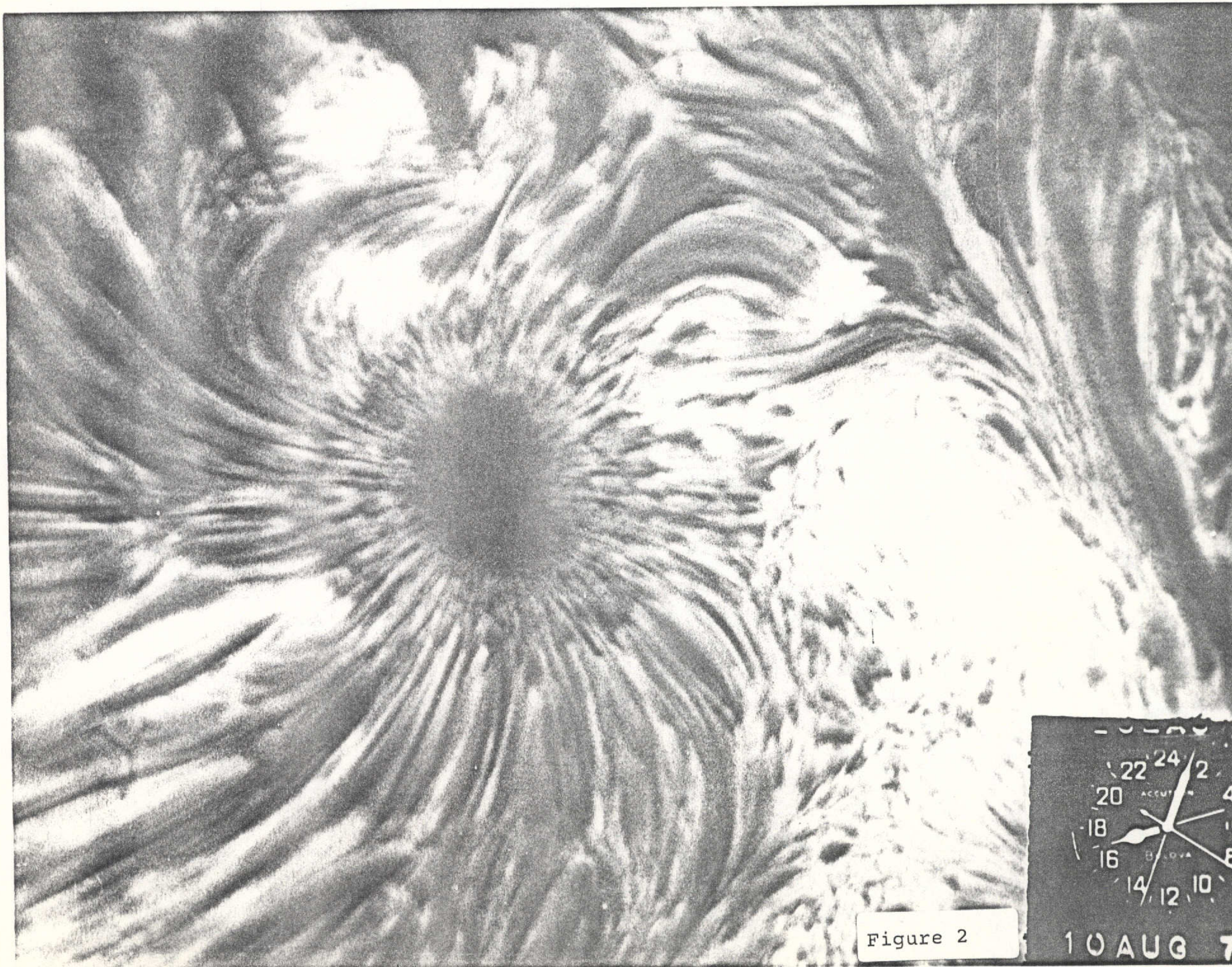


Figure 1



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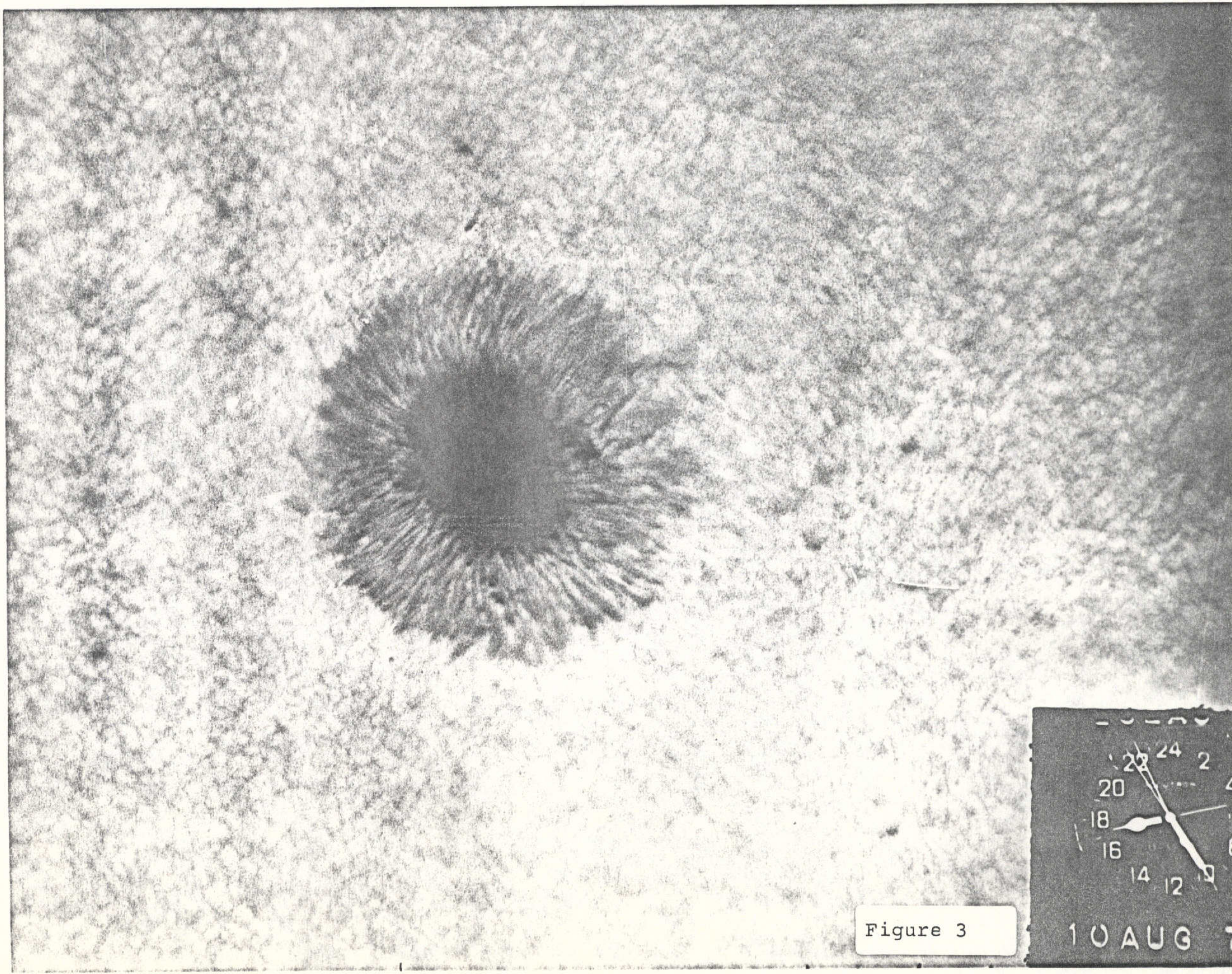

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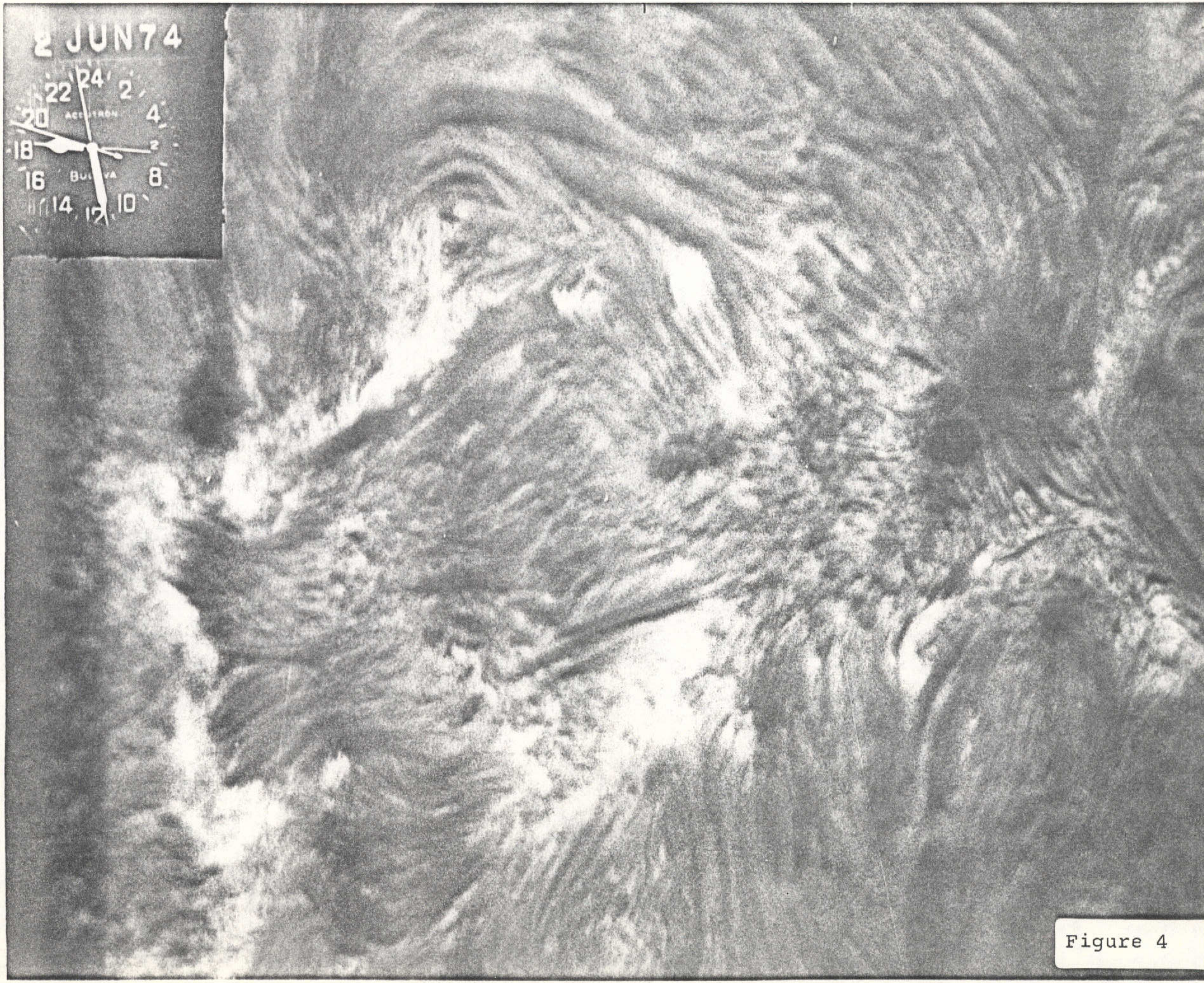

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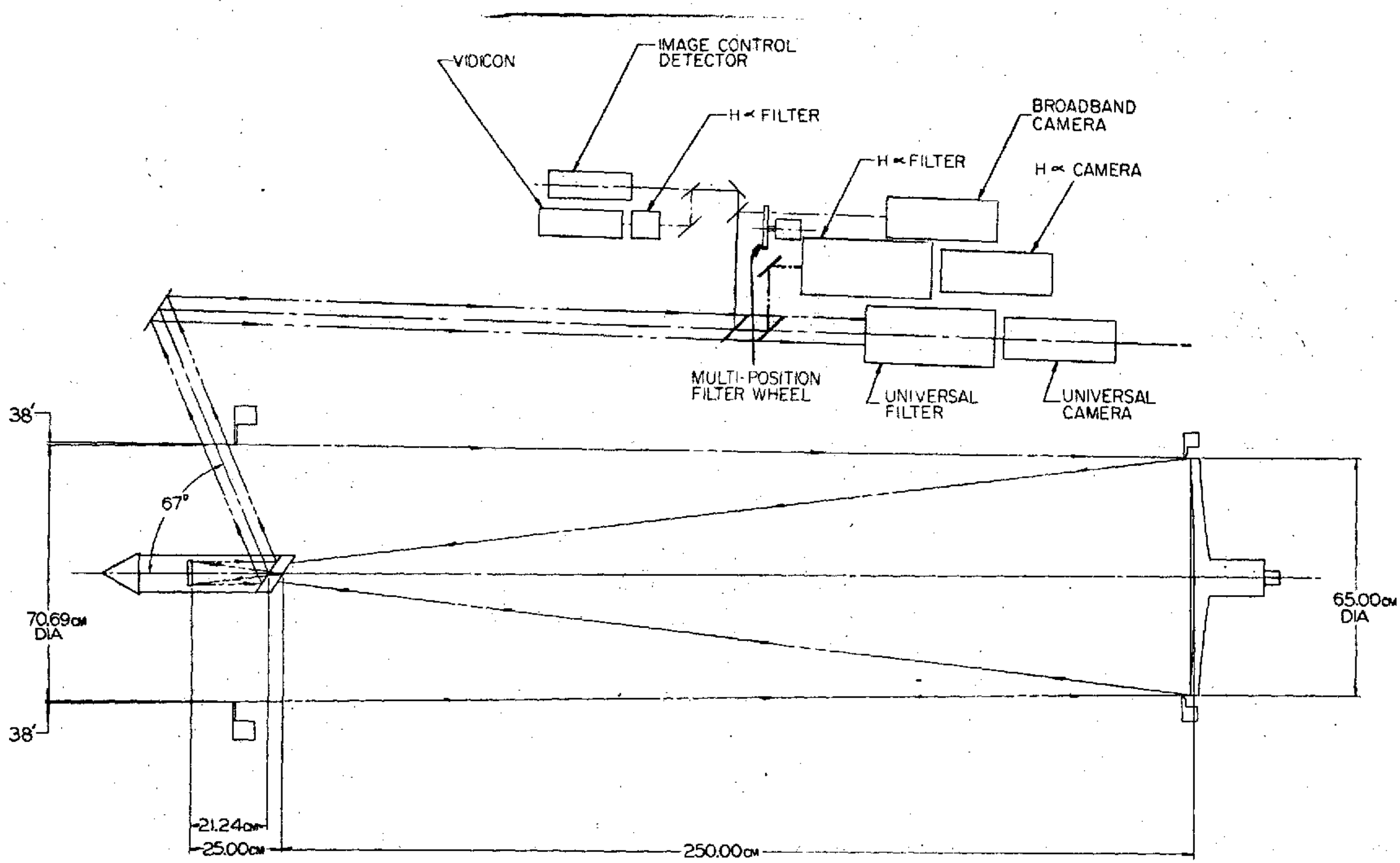
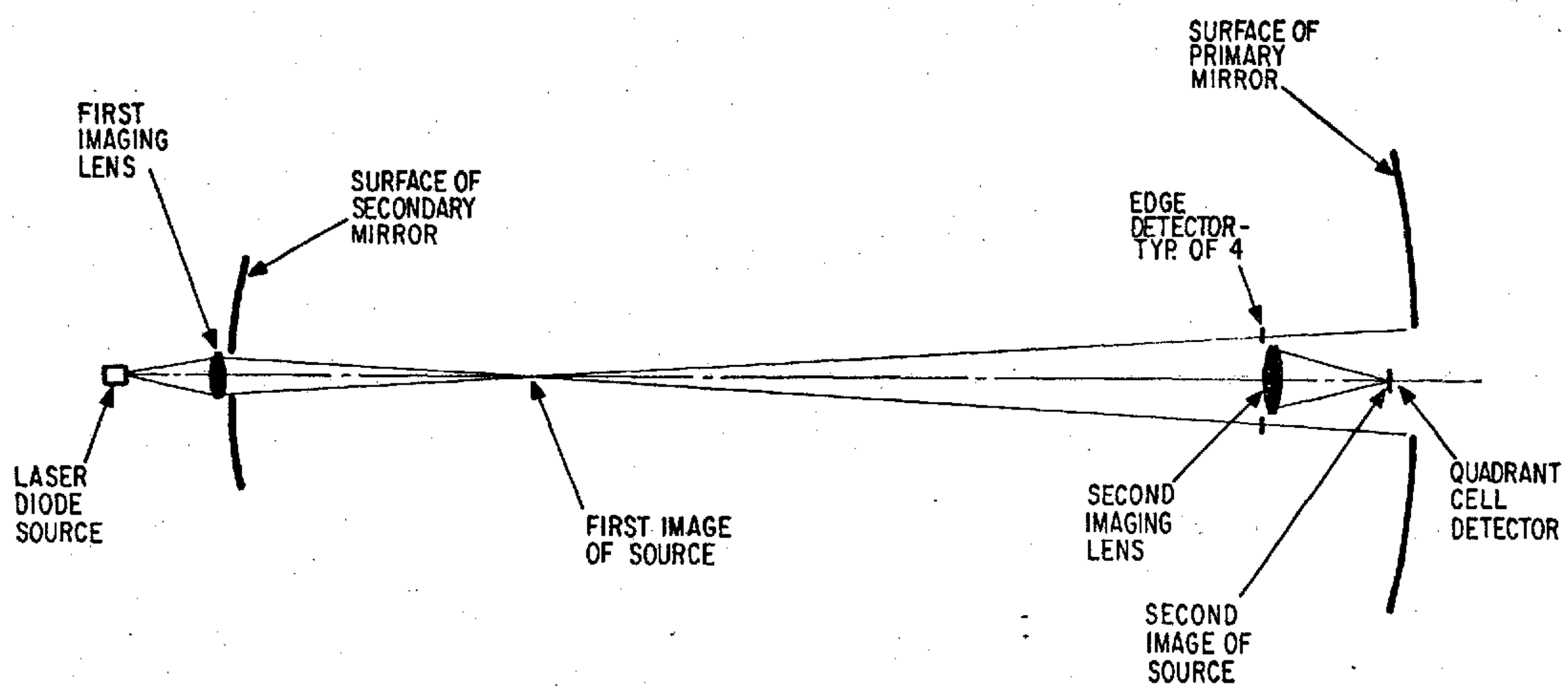


FOLDED GREGORIAN OPTICAL CONCEPT

Figure 5



INTERNAL ALIGNMENT SCHEME

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Figure 6

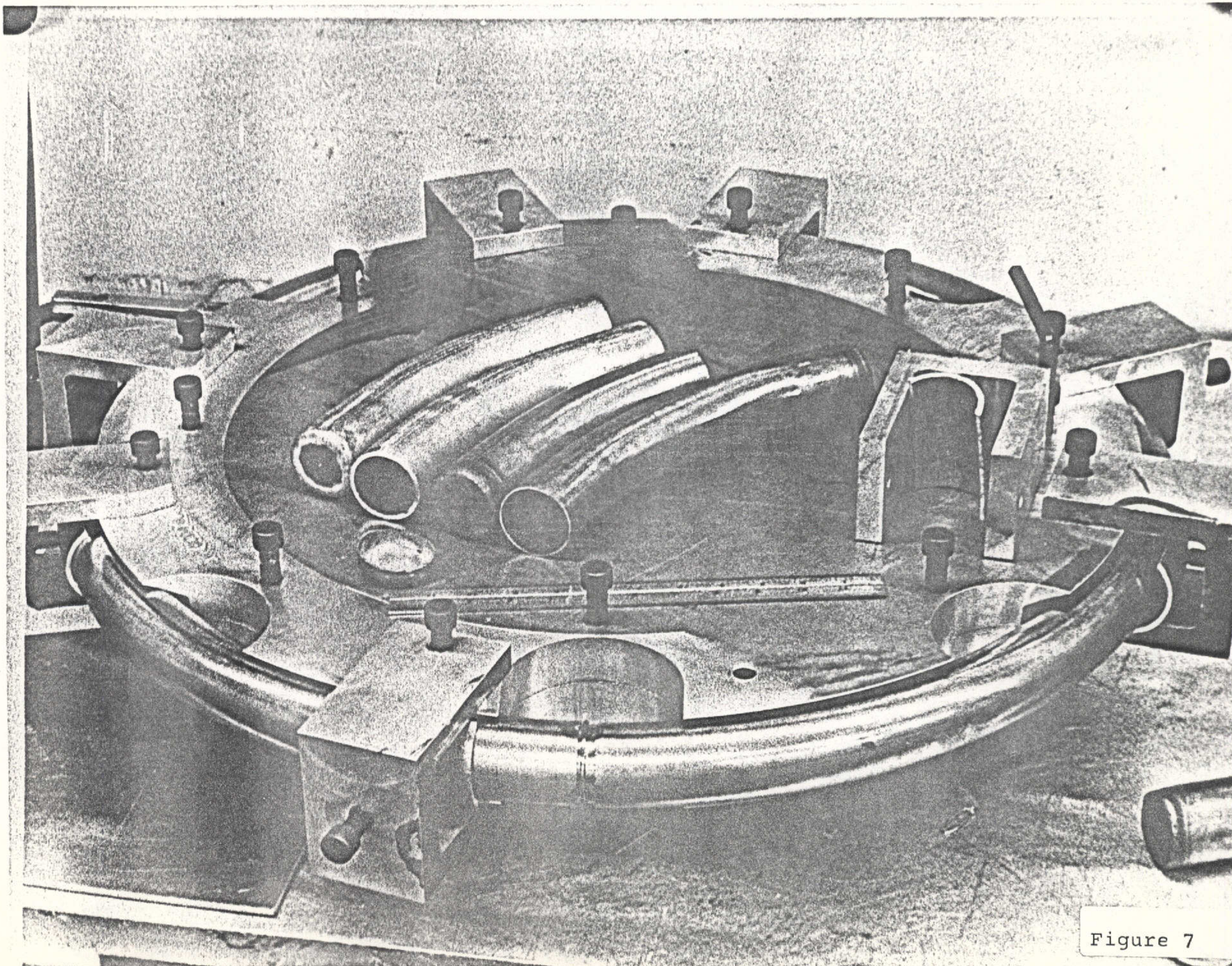
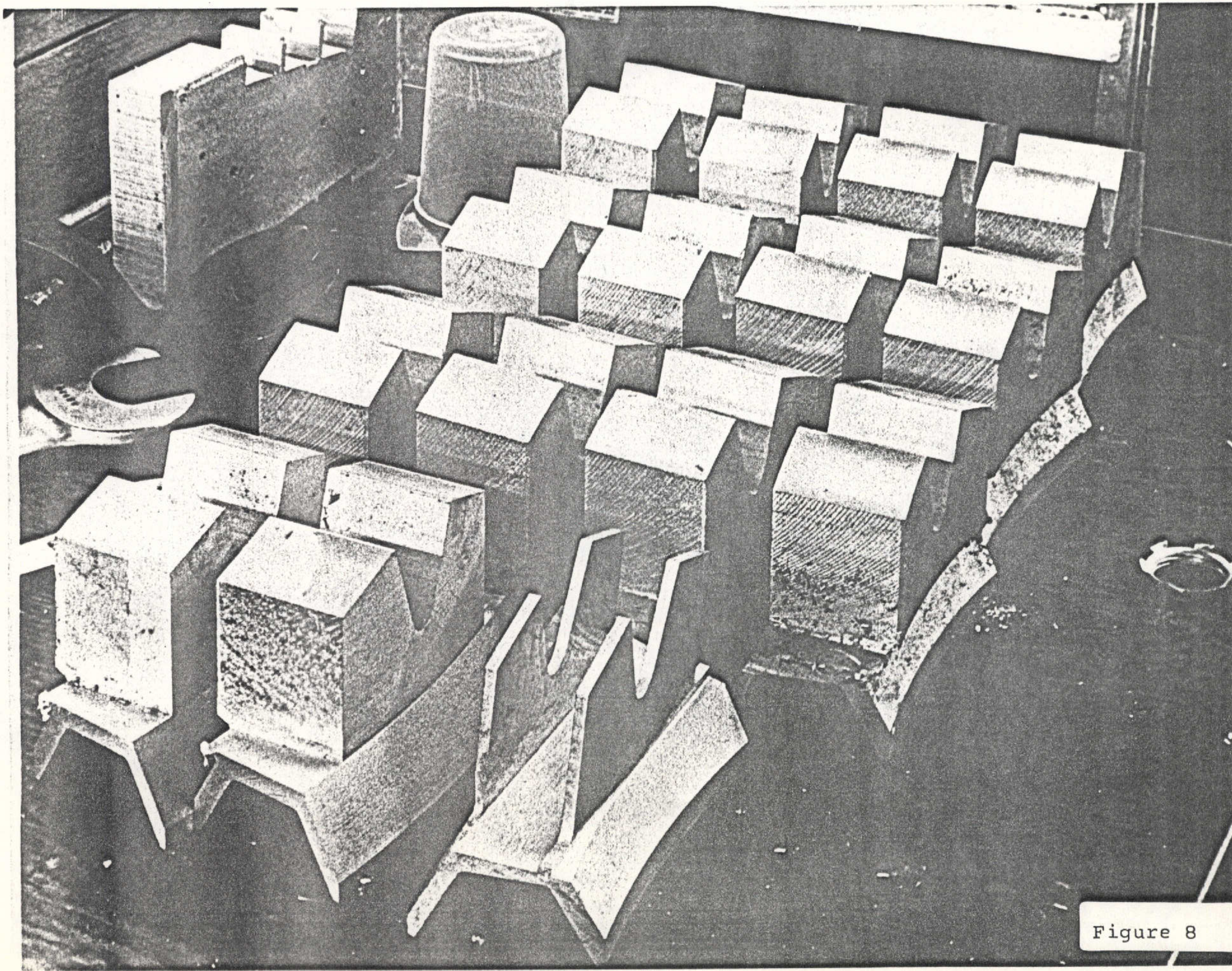


Figure 7



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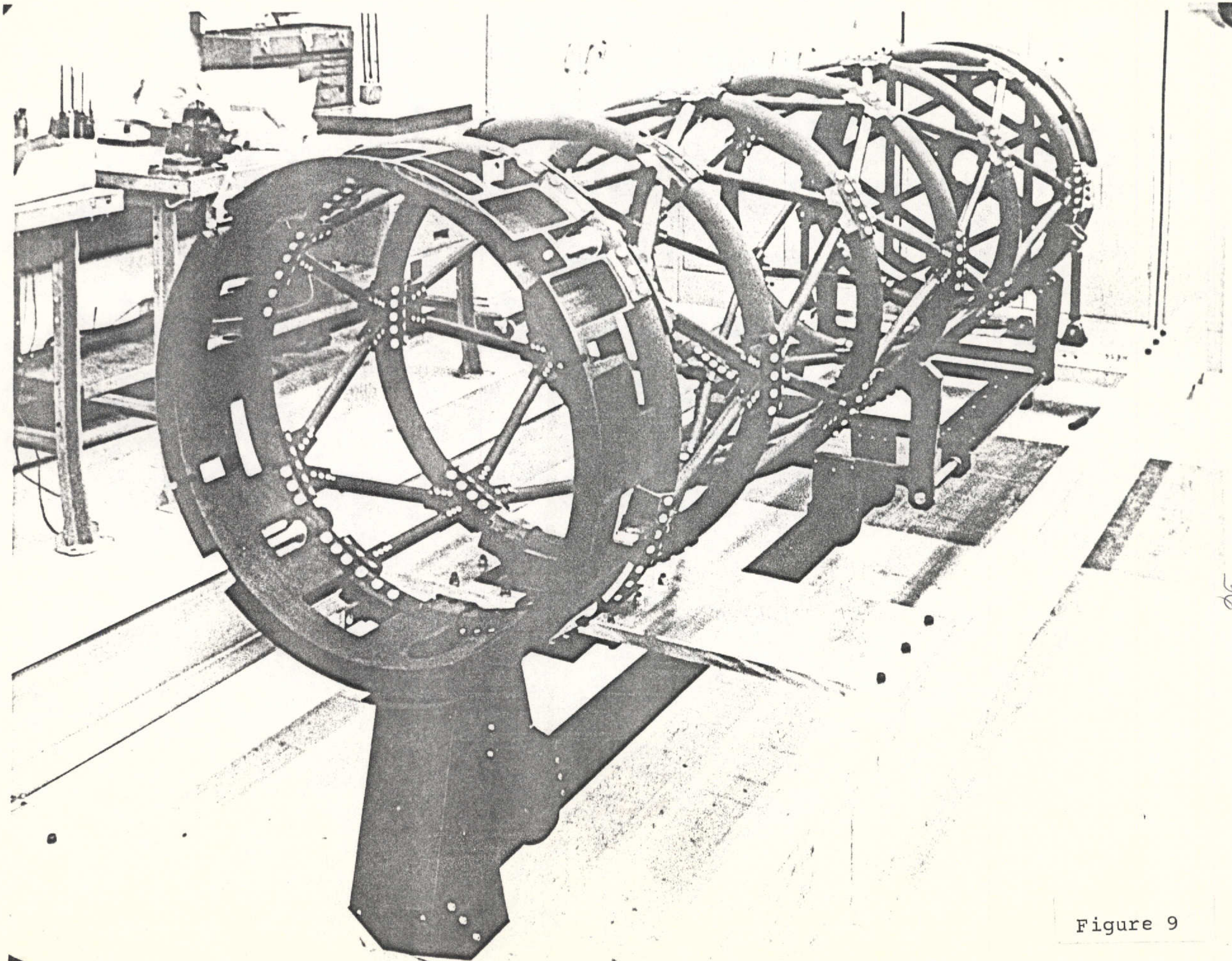

Figure 9

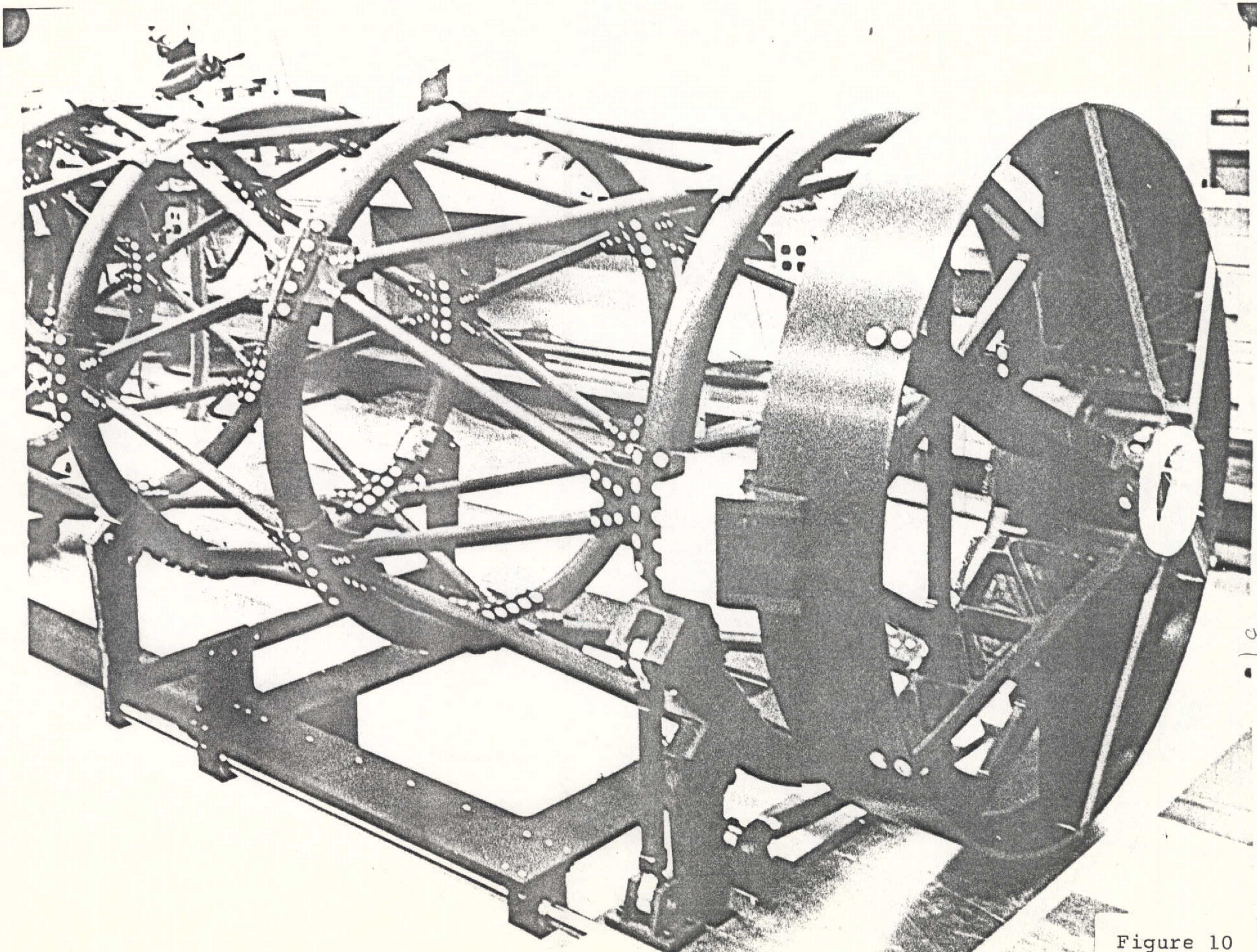

Figure 10

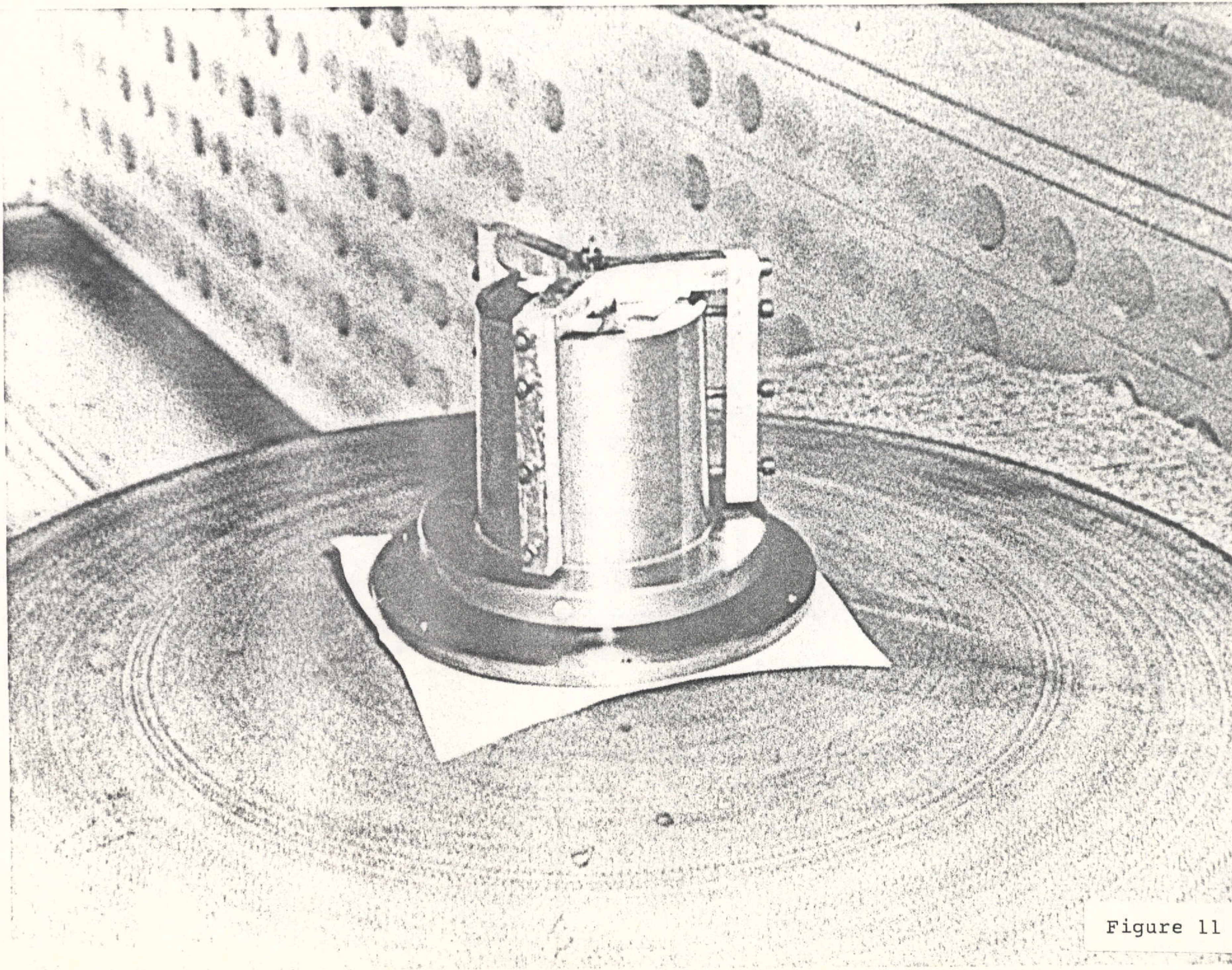

Figure 11

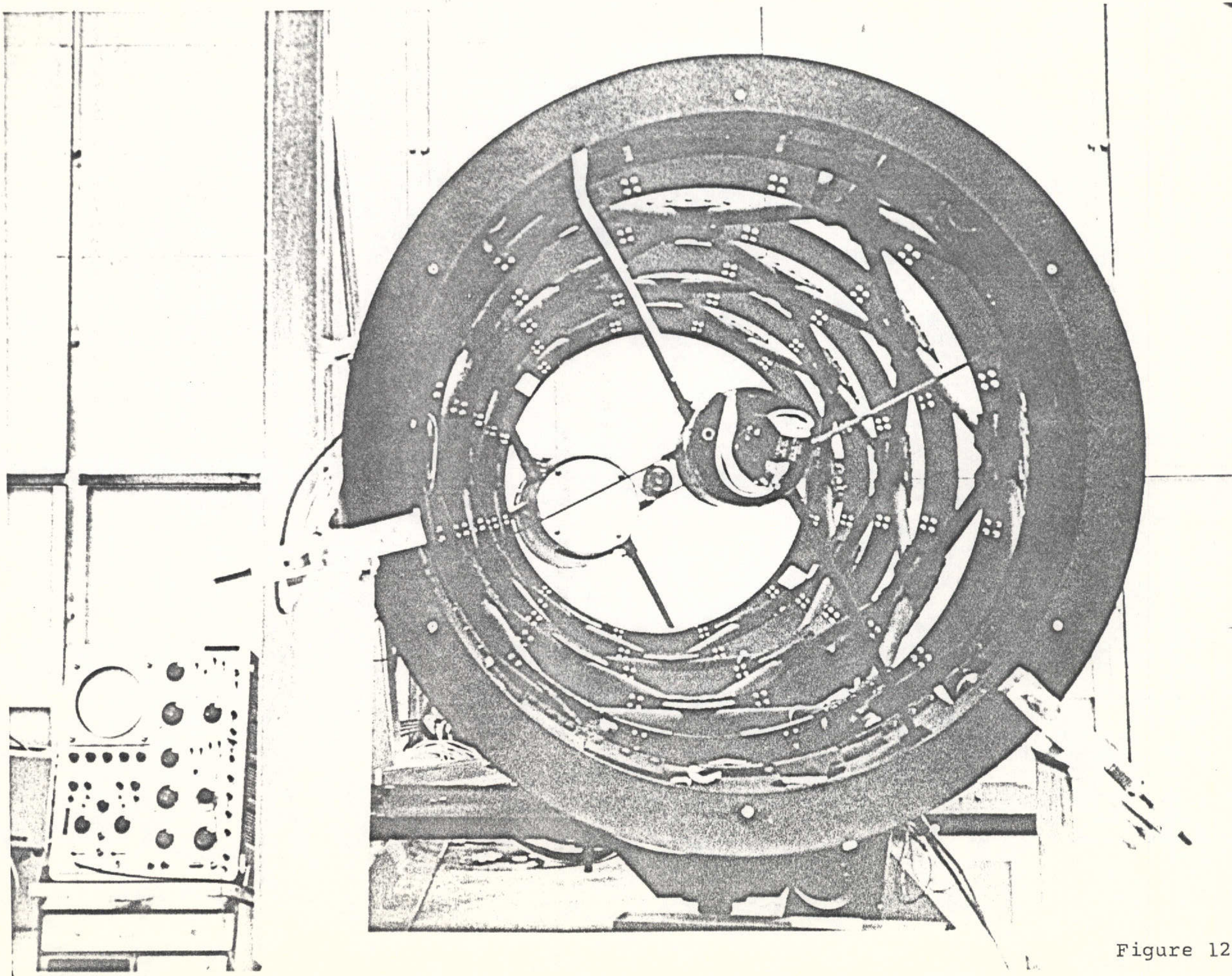

Figure 12

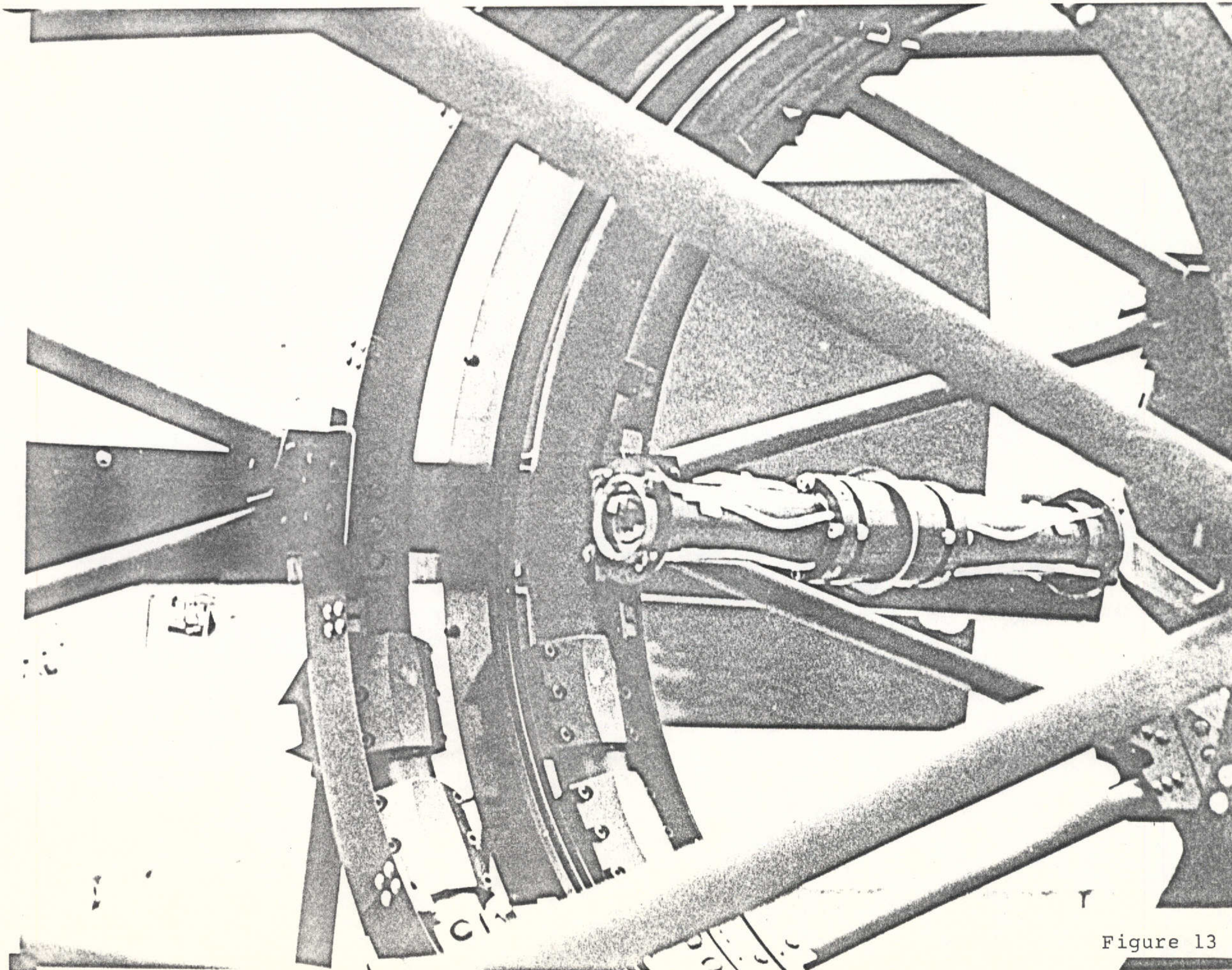

Figure 13

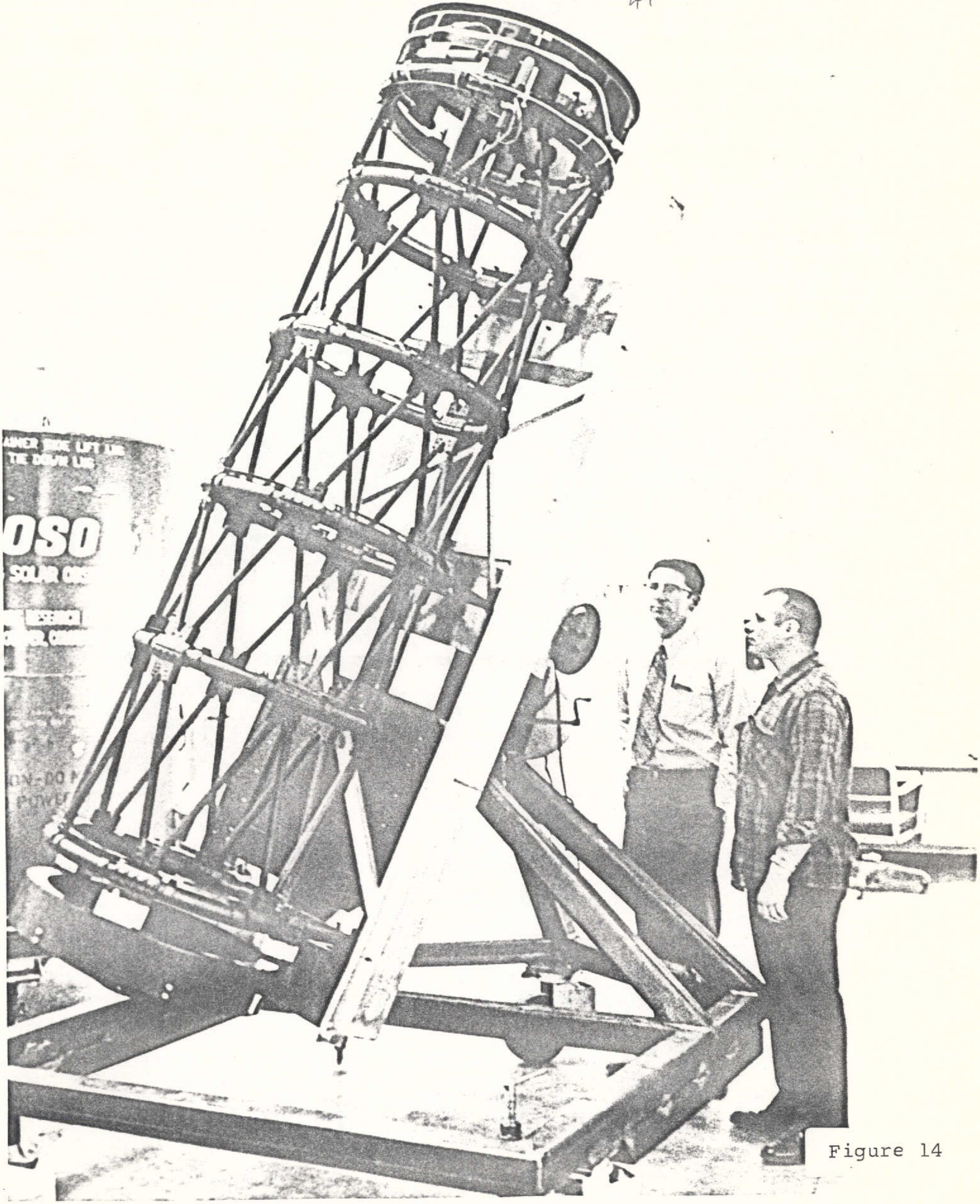

Figure 14

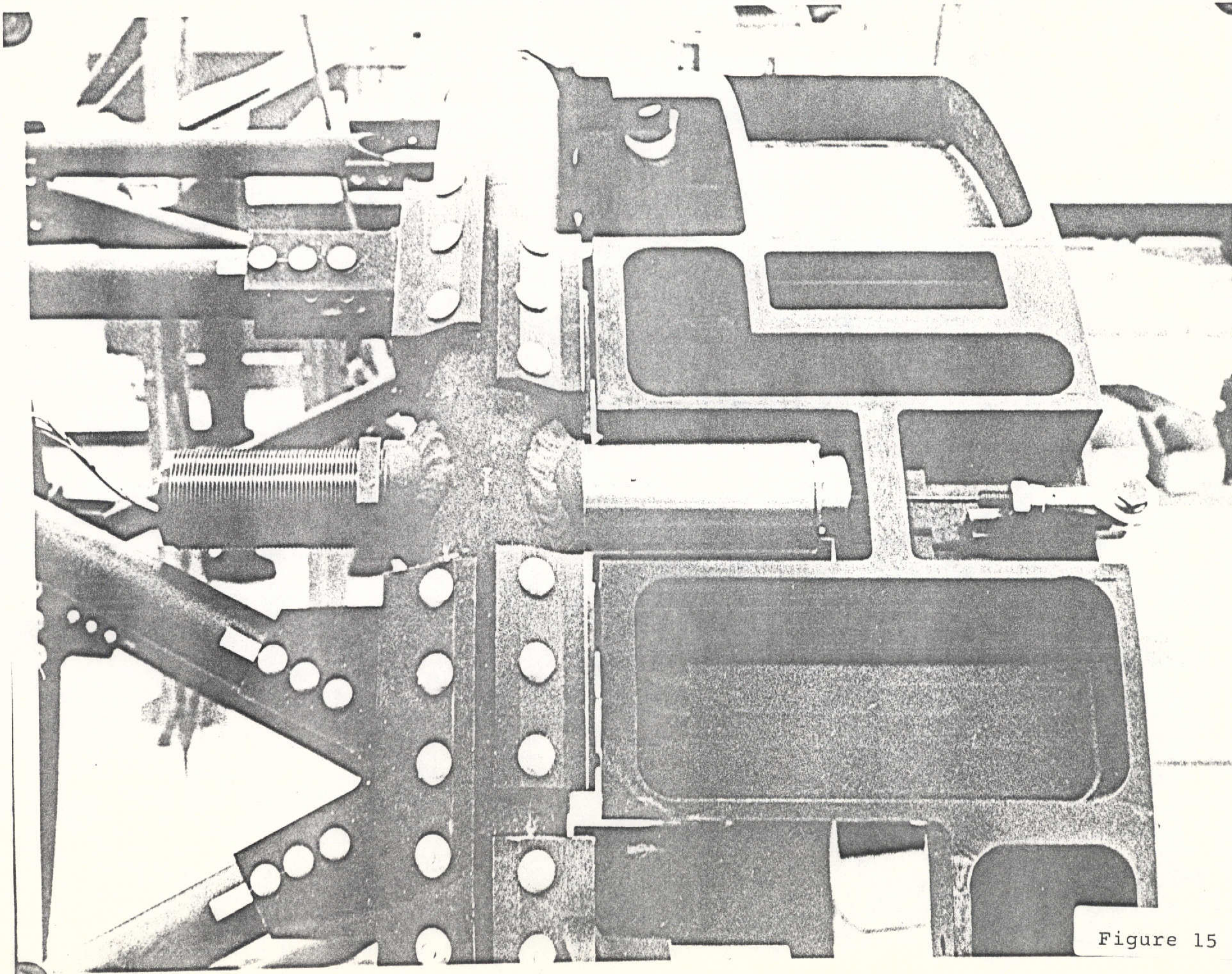

Figure 15

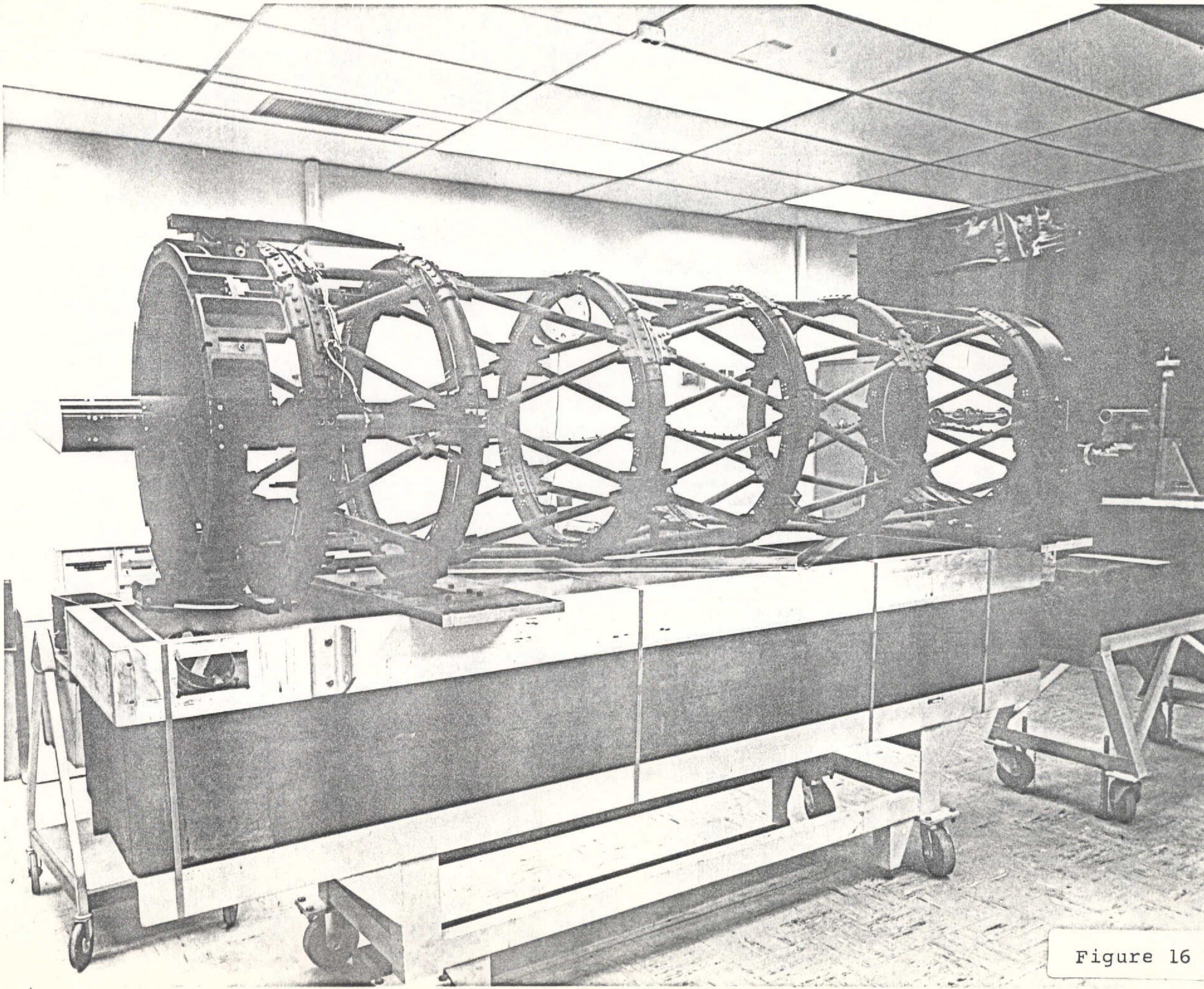

Figure 16

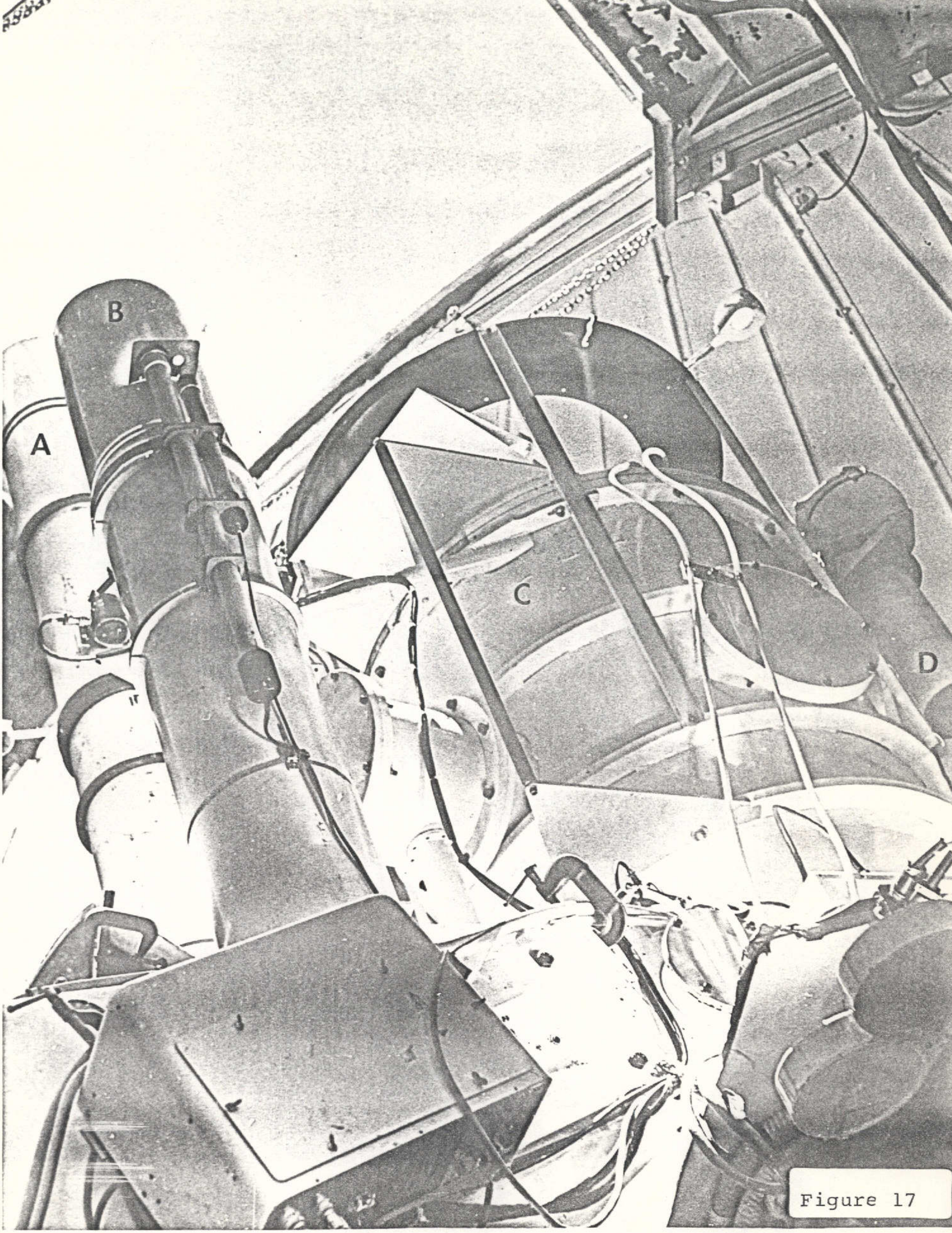

Figure 17

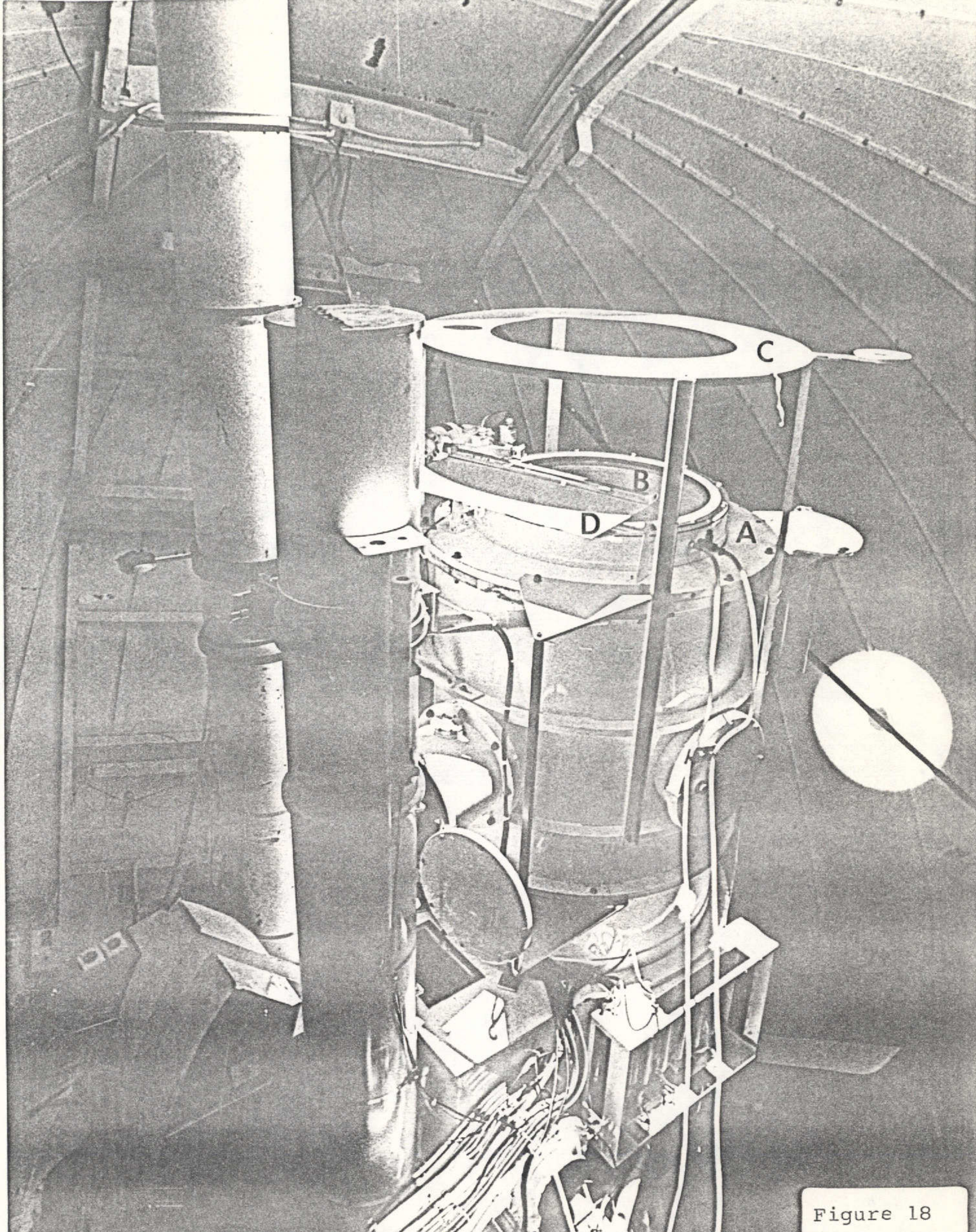

Figure 18

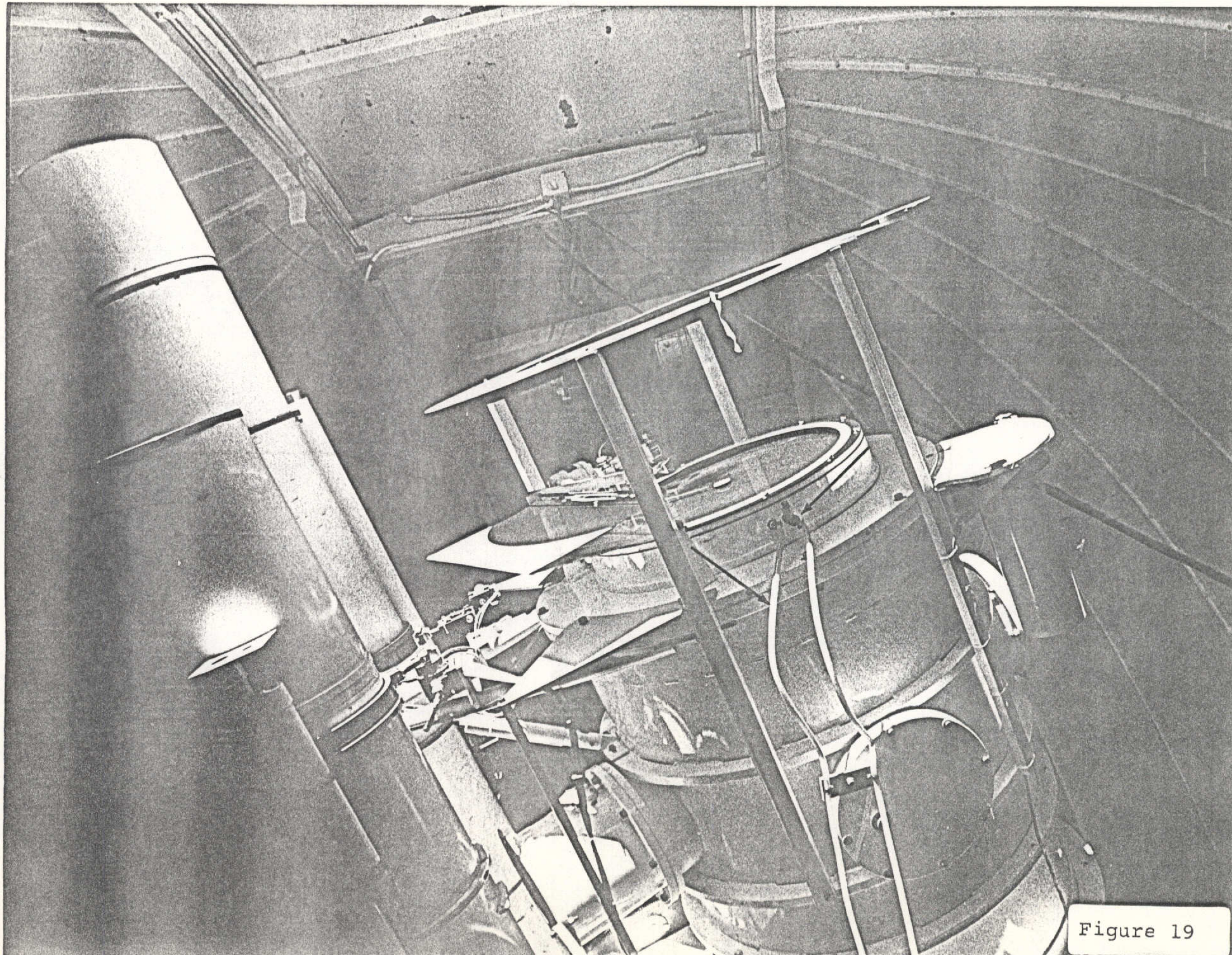

Figure 19

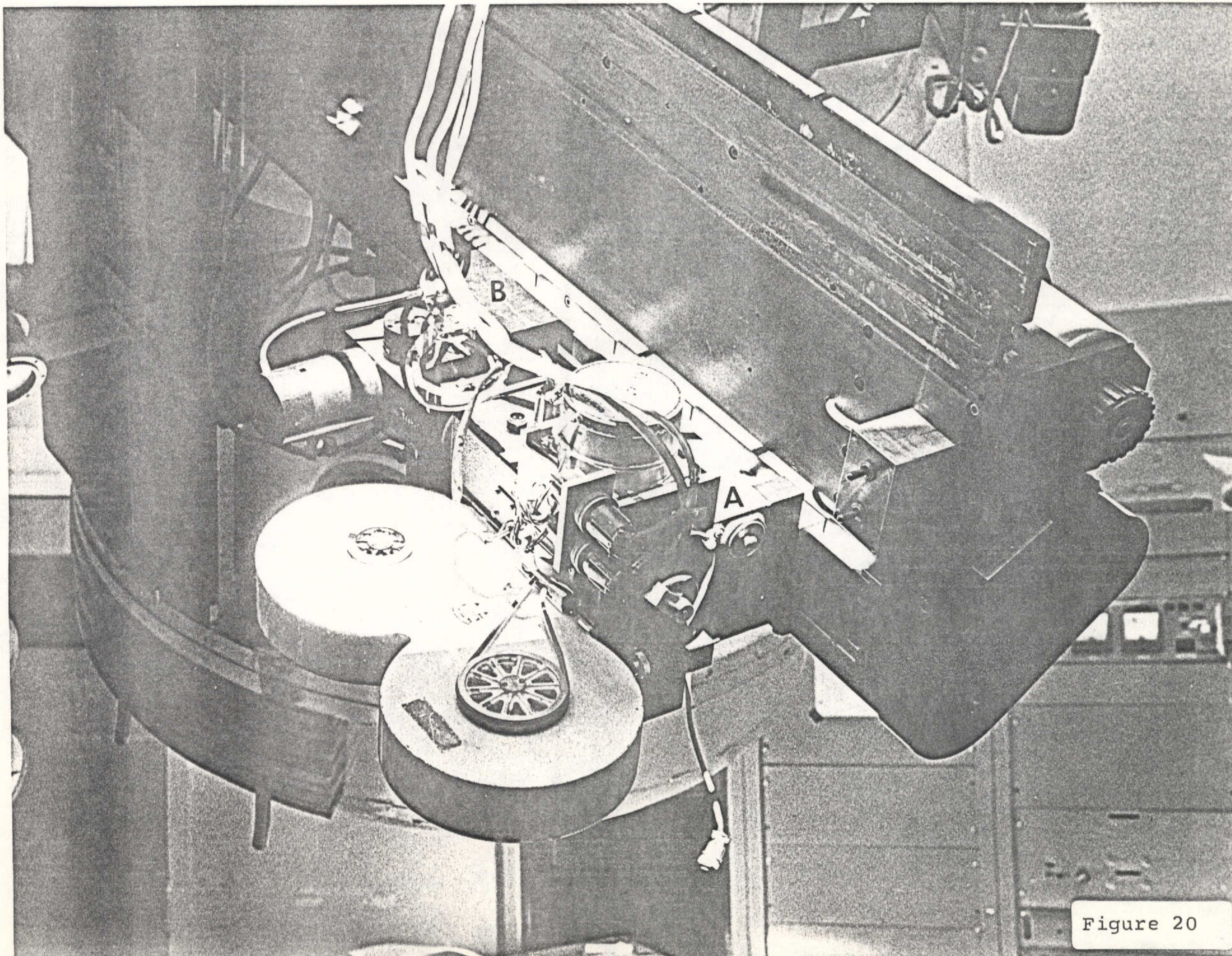

Figure 20

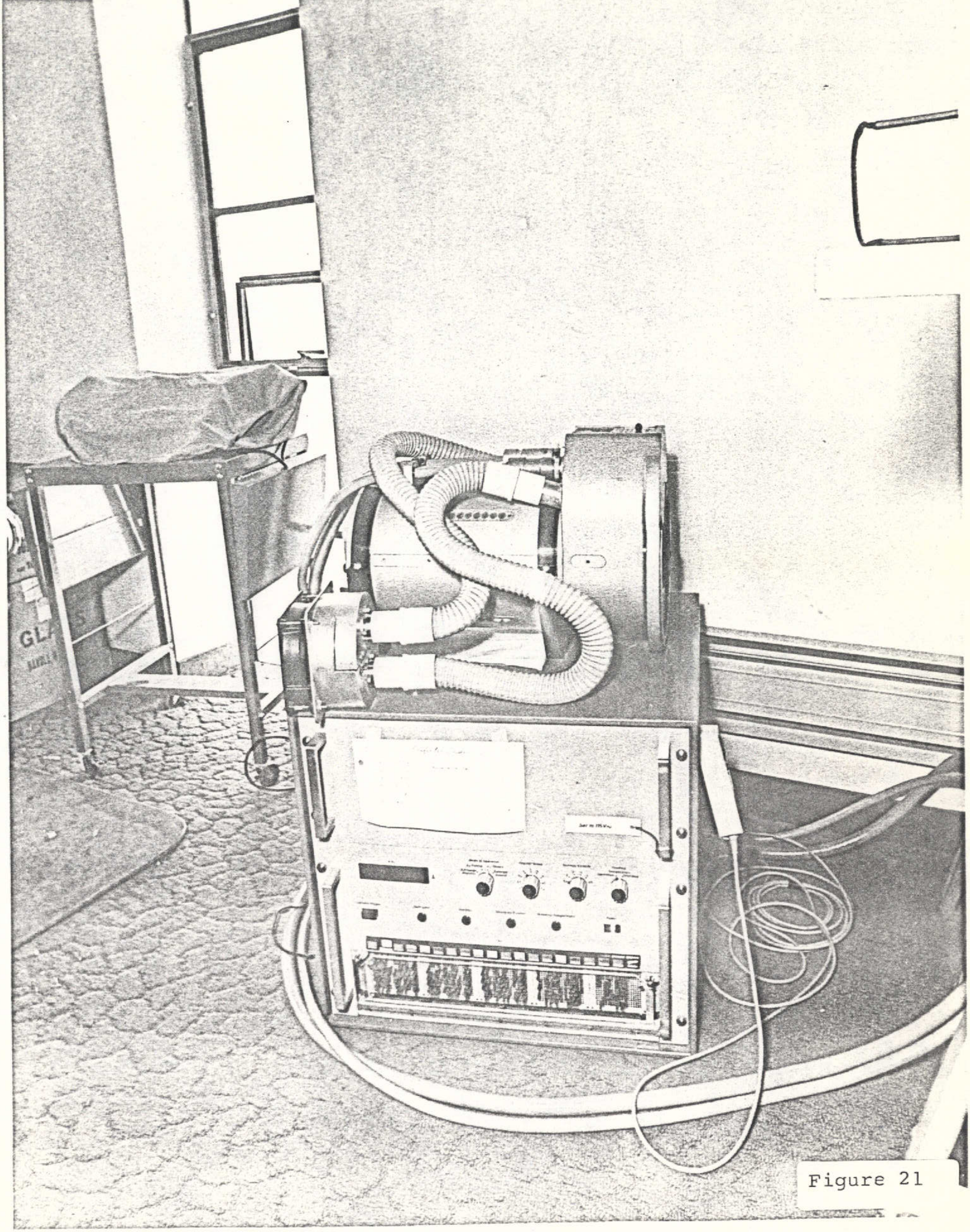

Figure 21

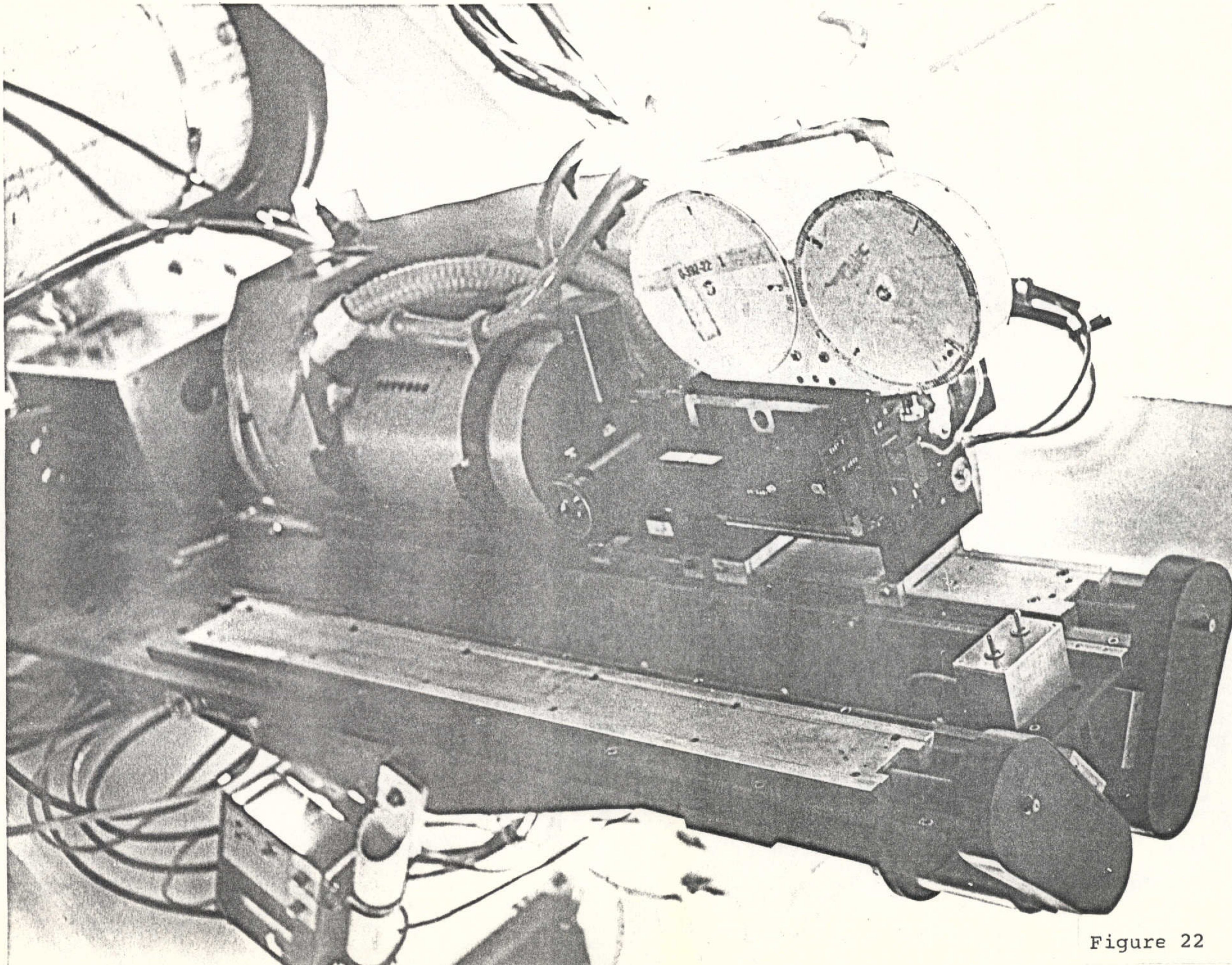

Figure 22

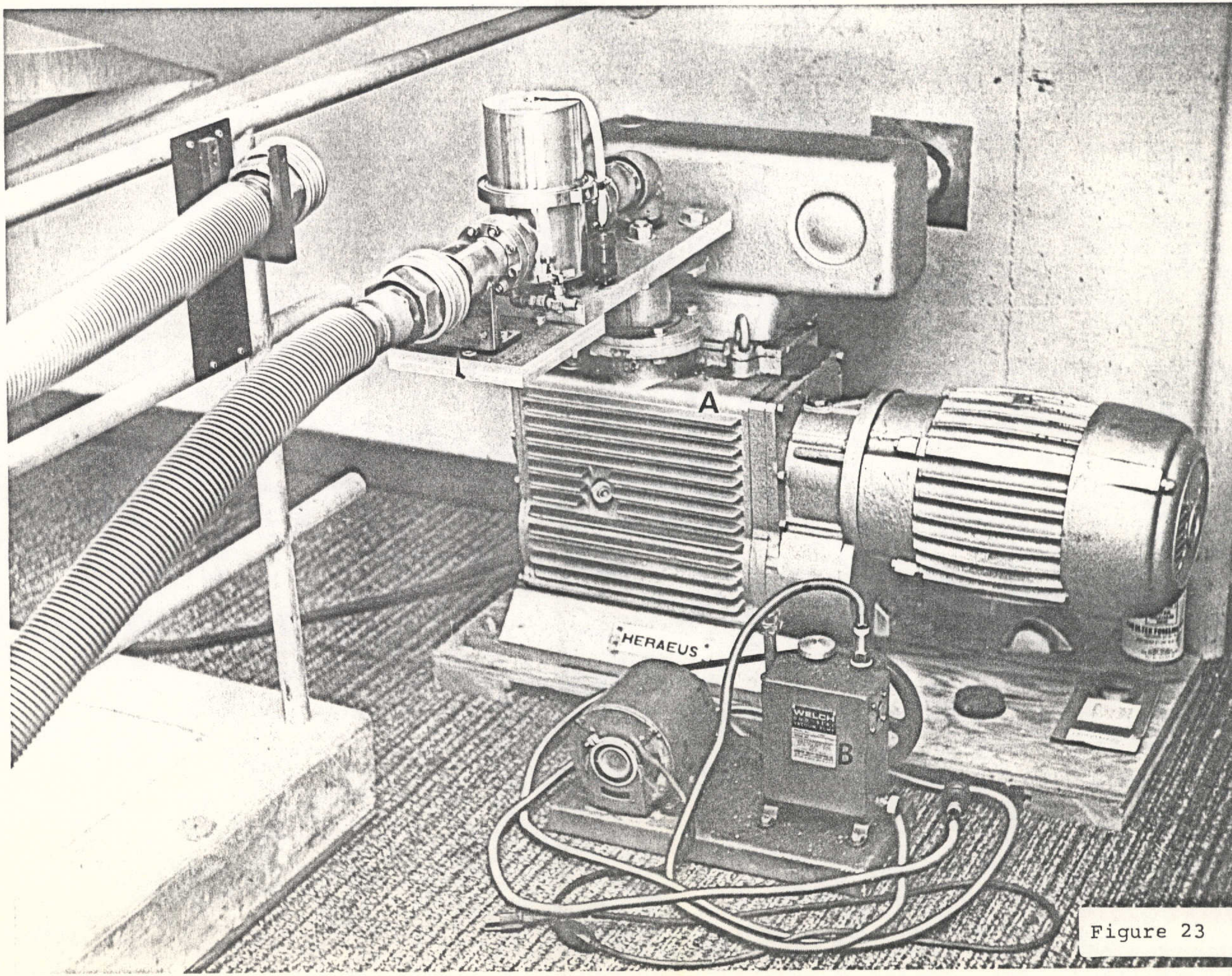

Figure 23